NPS-SP-95-001

NAVAL POSTGRADUATE SCHOOL
Monterey, California

DESIGN AND ANALYSIS OF THE HOUSING OF THE COMMUNICATION PAYLOAD OF THE PETITE AMATEUR NAVY SATELLITE (PANSAT)

by

Olaf Gericke

September 1995

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Prepared for: Unversitaet der Bundeswehr Muenchen
85579 Neubiberg, Germany

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The report was prepared by:

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE
	September 1995	Technical Report

4. TITLE AND SUBTITLE
DESIGN AND ANALYSIS OF THE HOUSING OF THE COMMUNICATION PAYLOAD OF THE PETITE AMATEUR NAVY SATELLITE (PANSAT) USING I-DEAS

5. FUNDING NUMBERS

6. AUTHOR(S) Olaf Gericke

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)

Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

NPS-SP-95-001

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Unversitaet der Bundeswehr Muenchen
85579 Neubiberg , GERMANY

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the US Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
In this thesis, the housing of the Communication Payload of the Petite Amateur Navy Satellite (PANSAT) is designed and analysed with the help of a software programm called I-DEAS. Providing enough stiffness, minimizing electomagnetic interference (EMI) and guaranteeing manufacturability in the extreme physical constraint imposed by the configuration of the satellite are the main goals. In addition a finite element analysis is performed.

14. SUBJECT TERMS
Design and Analysis of the housing
of the Communidation Payload of PANSAT

15. NUMBER OF PAGES: 60

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

ACKNOWLEDGMENT

Numerous individuals assisted me in completing this thesis through advice, encouragement, technical expertise. Many thanks to their invaluable contributions.

Of those who helped me, a few deserve special mention. Without the great effort and help of **Professor LIESS** and **Professor PANHOLZER** this thesis research would not have been possible. Performing the thesis in Monterey has been an exceptional invaluable experience. The SSAG PANSAT Engineering Staff were leading lights and a source of technical knowledge. I would like to express my thanks to Glenn **HARRELL**, Jim **HORNING,** Todd **MORRIS,** David **RIGMAIDEN** and Dan **SAKODA** for all their help and contribution.

Last, but far from least, I want to thank my wife **Heike** who always supported me with love and encouragement though mainly being half a world apart from me. Without all of these individuals this thesis would not have been written.

ABSTRACT

The Naval Postgraduate School's (NPS) Space Systems Academic Group is developing the Petite Amateur Navy Satellite (PANSAT), a small satellite for digital store-and-forward communication in the amateur frequency band. This thesis describes the design and the analysis of the communication payload housing of PANSAT.

The payload consists of four circuit boards. The main challenge is to provide enough stiffness and minimize electromagnetic interference within the small amount of space determined by other parts surrounding the housing. The design of this particular housing is especially demanding and requires paying a lot of attention to details. Many factors, including launch loads, board weight, component size, orientation, and mounting must be considered.

A particular aspect of this housing is the fact that there are an unusual number of electrical connectors involved in this design. Complicating this issue is the extreme physical constraint imposed by the configuration of the satellite.

The structure as well as the boards are analyzed using classical hand calculation methods and more sophisticated methods, using SDRC® I-DEAS design software. In addition, a finite element analyses is performed using the I-DEAS finite element application which allows to model all structures in great detail mathematically. It also permits to examine the behavior of these structures under all possible load conditions, static as well as dynamic.

Another important aspect of this design is to guarantee manufacturability. The complexity of this housing makes it mandatory that the design be carried out in close cooperation with the machinist who is responsible for the actual manufacturing of these parts.

The analysis results show that the structure of the housing is very robust and most likely will accommodate all the requirements.

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I. INTRODUCTION

A. BACKGROUND

PETITE NAVY AMATEUR SATELLITE (PANSAT)

PANSAT was initiated in 1989 to provide interdisciplinary educational opportunities in space related areas to prepare postgraduate students for follow-on work in space systems acquisition and design, and to develop a cadre of engineers and technicians at the Naval Postgraduate School (NPS) capable of developing and producing space qualified hardware. The current PANSAT design (Fig. 1A) is the result of five years of research by NPS thesis students and the personnel of the Space Systems Academic Group (SSAG).

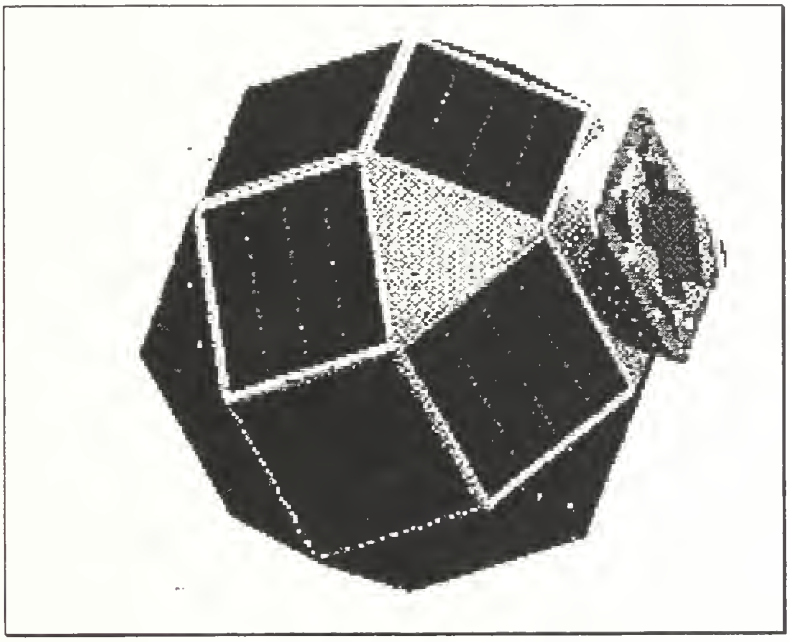


Figure 1A. PANSAT

The payload will be a direct sequence spread spectrum differentially coded, binary phase shift keyed (BPSK) communication system with an operating frequency of 436.5 MHz. The store and forward communication will allow amateur radio operators to send and receive messages during several short communication windows each day.

The spacecraft weighs approximately 150 pounds, has a diameter of about 19 inches, and is being designed to launch as a secondary payload from the space shuttle as part of the Hitchhiker Program. PANSAT has no attitude control and will tumble freely. Operational life is expected to be two years. PANSAT will orbit at an inclination between 28.5° and 51.6° and an altitude between 160-220 nautical miles which will provide sufficient coverage for up to ten minutes of communication between the spacecraft and NPS. The launch sequence as a Complex Autonomous Payload (CAP) is shown in Fig. 1. A pictorial presentation of the mission is shown in Fig. 2 [Ref.6].

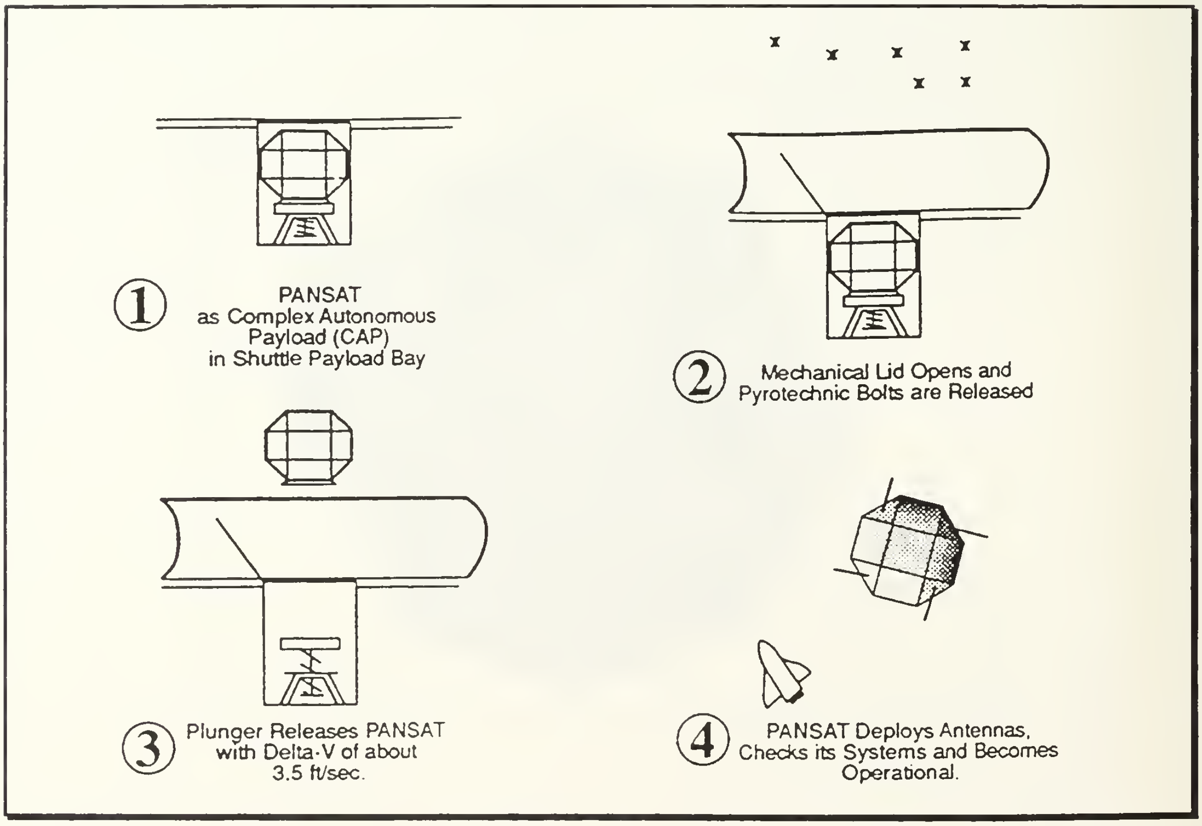


Figure 1. PANSAT Launch Sequence as a CAP Payload

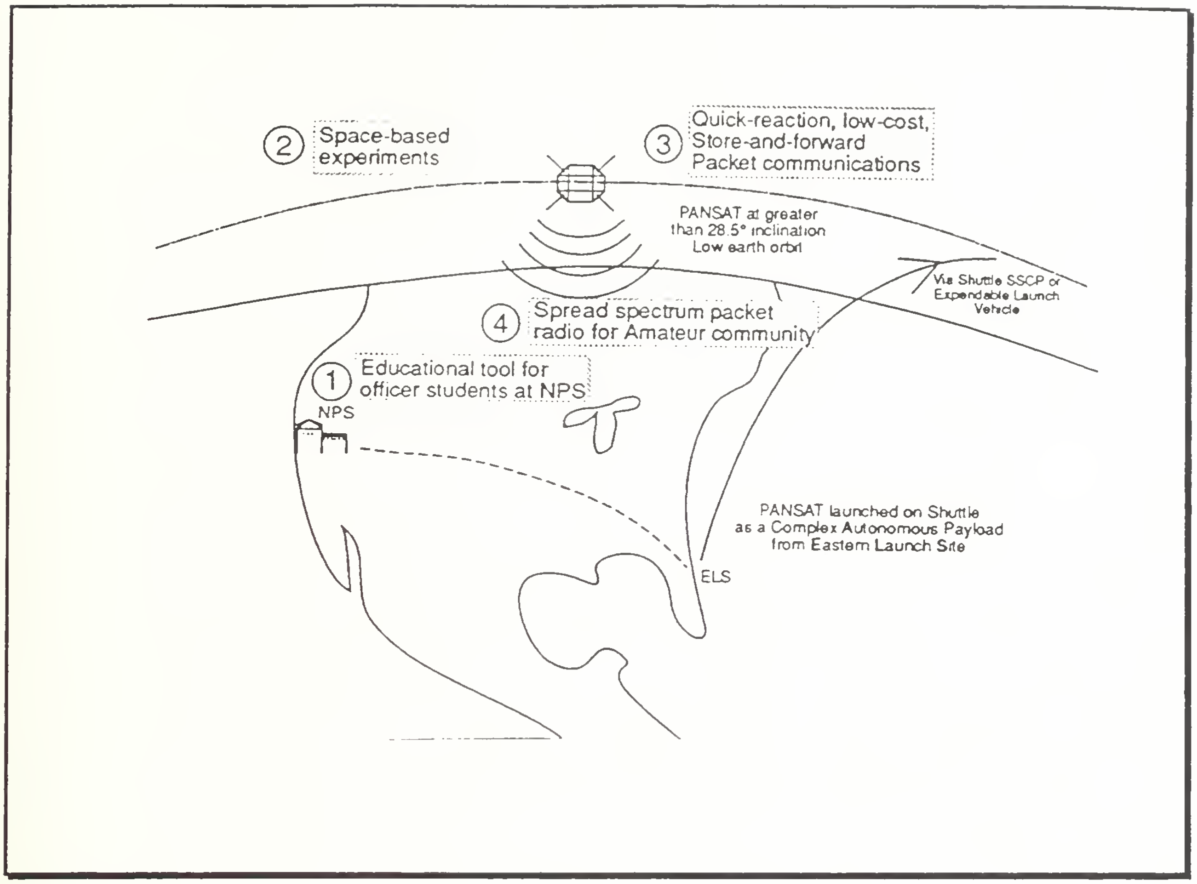


Figure 2. PANSAT Mission Overview

The PANSAT structure is made of aluminum 6061-T6 and built around a main load bearing cylinder connected to the lower equipment plate. The satellite is a tumbler, and since maximizing surface area increases power generation the solar panels are mounted on the space craft skin. A 26-sided polyhedron was the chosen configuration.

PANSAT has three major subsystems:

- the Electrical Power Subsystem (EPS)
- the Digital Control Subsystem (DCS)
- the Communication Subsystem (COMMS)

The COMMS will be placed in the housing designed and analysed in this thesis. The structure is about 19 inches wide as shown in figure 3.

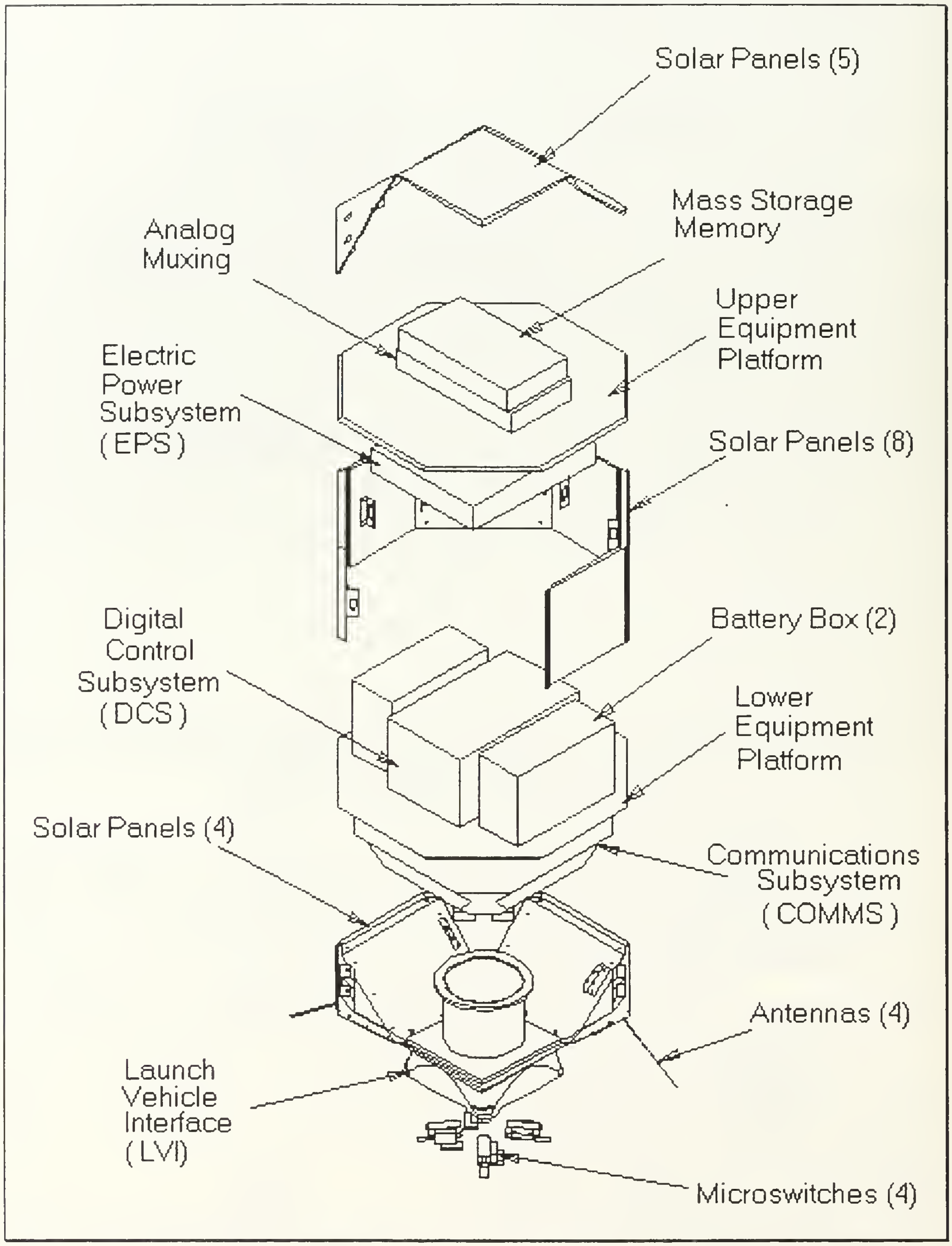


Figure 3. PANSAT Configuration

B. SCOPE OF THESIS

The core of the thesis was to design and test the housing of the communication payload, called the **RF- HOUSING**. The RF-Housing is fully enclosed and will be attached to the lower equipment platform. The main problems are the small space, EMI shielding and how to fit everything together. Additionally, theoretical structural analysis was contucted to test the structural stiffness. The communication payload includes four circuit boards which have the following names:

- the **POWER-BOARD,** which supplies the entire RF unit with power

- the **RF-BOARD**, which is the biggest board due to two oscillators, which are mounted on it. The oscillators are the largest components used inside the housing.

- the **LNA-BOARD,** which houses low noise amplifiers

- the **HPA-BOARD,** on which high power amplifiers are mounted

II. Structural Design

A. Requirements

1. Launch Environment

Launch loads for the Shuttle are due to the acoustic environment of the payload bay and thrust forces. The structure has to withstand launch loads, shocks, ground qualification and acceptance test loads and on-orbit loads.

All components lighter than 20 lb. must be able to withstand a **load vector of 40 g's** in the most critical direction and 20 g's in all other directions as well as have a natural frequency of 35 Hz or greater (desirable to have the lowest frequency above 50 Hz). If the predicted natural **frequency** is below **100 Hz** its lowest cantilevered frequency has to be verified by test [Ref. 1].

The minimum frequency requirements are imposed in order to decouple the spacecraft main resonance from the launch vehicle dynamic excitation, thus maintaining the spacecraft dynamic response to within acceptable limits and limiting the environmental impact on the equipment. Meeting minimum frequency requirements greatly simplifies the structure design and increases the overall spacecraft weight in general.

The equipment shall be subjected to structural testing at 1.25 times the limit loads and show positive margins of safety by analysis at **1.4** times the limit load for all ultimate failure modes such as material fracture or buckling. Alternatively the customer may qualify the equipment by analysis alone by showing positive **margins of safety** at 2.0 times the limit loads for material yield and **2.6** times the limit loads for ultimate failure modes.

English units are used mainly because of their use in aerospace industry and from vendor information on aluminum.

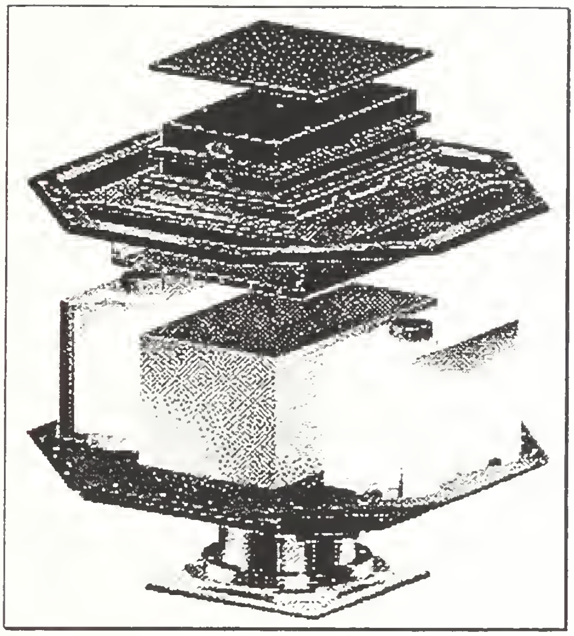


Figure 3a. PANSAT Configuration

2. Envelope

The size of the housing is limited by the lower equipment plate, the baseplate, the support cylinder and the solar panels (Fig. 3), which leads to an envelope shown in Appendix C. The RF housing was desiged into the top portion of this envelope, mounted to the lower equipment plate, to provide enough space for a filter and a relay and other components located under the lower equipment platform. Also connecting the solar panels (5) under the RF housing to the housings above the lower equipment platform had to be considered, as well as the connecting wires from the micro switches at the bottom of the satellite.

The design of the housing was initiated by going to the envelope edge directly below the lower equipment plate as far as possible and providing as much space as possible for the boards. As a result the distance between the housing and the solar panels approaches at its narrowest point 0.2 inches. Therefore a feed through of parts between the panels the and housing is not recommended. Connectors and cables are brought through the housing itself. This makes joining in the end easier but also causes interference problems.

3. Electromagnetic Interference (EMI)

Electromagnetic Interference (EMI), also called noise, is an issue which can be of great concern in electronic systems. Circuits operating in close proximity to each other may affect each other negatively, perhaps to the point where the system containing the circuits does not work . The exact manner in which circuits interfere with each other is difficult to predict. Actual testing with all systems in full operation is needed.

While it is difficult to know if circuits will interfere with each other, there are several points which should be considered during the design to minimize any potential EMI issues. The designer may consider these points and incorporate them during the process, or may ignore them and then analyze the finished product for noise effects. The first method is referred to as the "systems approach". The second method is called the "crisis approach". Examining EMI with the "systems approach" is recommended. It is usually much easier and less expensive to correct potential problems at this point than to put a "Band-Aid" on problems discovered after the design is complete [Ref.3].

The RF-Housing contains four boards which appear to be EMI sensitive components, or significant noise sources. This will not be verified until testing. Because of this, a systems approach is used here to include EMI reduction features in the design to minimize any potential problems. Actual testing will be needed to confirm that no EMI problems exist.

EMI Shielding

To reduce EMI, shielding may be used. A shield is defined as a metallic partition placed between two regions of space [Ref.2]. It contains EM fields by surrounding the noise source. This helps provide protection for EMI susceptible equipment outside the source. It also helps keep radiation generated by other subsystems out. Shielding will minimize radiation effects, but precautions must be taken with cabling passing through

the shield. Cabling can easily conduct noise into or out of the system, which can make the shield virtually useless. The effect of a shield is a function of the material used and the presence of any holes or discontinuities. The PANSAT RF boards are enclosed in the housing. This housing meets primarily structural needs and also serves as a shield.

Shielding Material

As the EM wave propagates, it will impinge the shield and will be reflected and transmitted. The amount will depend on the material used. The energy transmitted will also be attenuated which is referred to as absorption loss. Absorption loss will increase as shield thickness increases.

A key factor is the skin depth of the EM wave. Skin depth is the distance the wave will travel until it has been attenuated to 37% of its original value. If the shield is at least as thick as the skin depth, a significant amount of the EM wave will be absorbed . Skin depth is a function of frequency and material.

All of the RF housing walls are at least 0.0625 inches thick. Most are thicker than this; for example the beams between the boards are 0.125 inches thick. From Table 1 it can be seen that the housing absorbs a considerable amount of EM energy except at the lowest frequencies.

Frequency (Hz)	Skin Depth (mils)
1,000.0	3.0
100.0	11.0
10.0	33.0
1.0	105.0

Table 1. Frequency and Skin Depth

Conclusion

All boards in the RF housing are multilayered and have ground and power planes. Most of the circuitry is analog and only a small portion is digital. This will significantly reduce the noise effects they experience and cause. Many of the problems increase with speed. The logic used by the digital portion is CMOS, which is fairly slow. Digital circuitry is most susceptible at speeds above 10 MHz, and PANSAT operates at less than 1 MHz [Ref.3].

Another device used by the RF system to minimize noise are ferrite beads. These beads are used to prevent noise generated by the digital circuitry from getting to the analog circuitry via conduction. Ferrite is a generic term for a class of non-conductive materials. The ferrite beads are particularly effective in damping out high frequency oscillations generated by switching transients. Because the RF system is mainly analog, uses multilayered boards with a ground plane and power plane, and uses ferrite beads, noise is not expected to be a problem.

Should EMI problems occur, EMI gaskets could be added between the lid and the housing along the walls separating the boards. Gaskets all around the edges of the pockets are not possible because the thickness of the side walls of the housing are only 0.065 inches, where it faces the cylinder support and the triangular panels.

B. MANUFACTURING

The mechanical design of the housing was dictated by the small space available and the concern of EMI shielding which lead to unusual circuit board shapes that ideally should be rectangular. The manufacturing of only one housing instead of four independent ones was chosen because the latter one would have been far more complicated and would have caused problems while fitting the parts together.

1. RF Housing

The RF housing is designed to support four electrical boards of different size and weight. It is made is made as a single part to help reduce problems when the parts are fitted together. For the design, aluminum 6061 - T6 is being used throughout, which has a high strength-to-weight ratio and good machining properties.

The whole structure has a minimum thickness of 1/16 in. and 4-40 screws are being used for fastening, providing a sufficient margin of safety as demonstrated in Appendix A. The housing will be milled out of a 14.2x14.2x1.235 inch piece of aluminum. Four main pockets, 14 through-holes and 89 holes will be have to milled. The maximum pocket depth will be .815 inches which could lead to complications while milling the part; but the depth increases in steps because all the pockets are surrounded by edges that are at least 0.25 inches wide to provide enough material for the attachment of the boards to the housing. Therefore the longest end-milling-distance will be 0.45 inches. To provide enough room for the circuit boards all corners will have to be as acute as possible. This is dictated by the machining equipment and the smallest end-mill being used, which will have a radius of 0.125 inches. The mechanical drawing in Appendix C gives the coordinates of all the edges that will have to be milled step by step, cutting the pockets deeper and deeper. The bottom thickness of the housing is only 0.07 inches and therefore very sensitive to displacement during the milling process. The five "tunnels"

located at the inner part of the housing will support the board and leave an opening to attach SMA-connectors from the bottom of the housing directly to the boards (and provide EMI shielding) after the boards and the lid have been joined with the housing. The thickness of these tunnels can be changed. Around the mounting holes of the boards there has to be enough material and enough space has to be provided to connect the cables to the boards. This design makes the testing after assembly a lot easier.

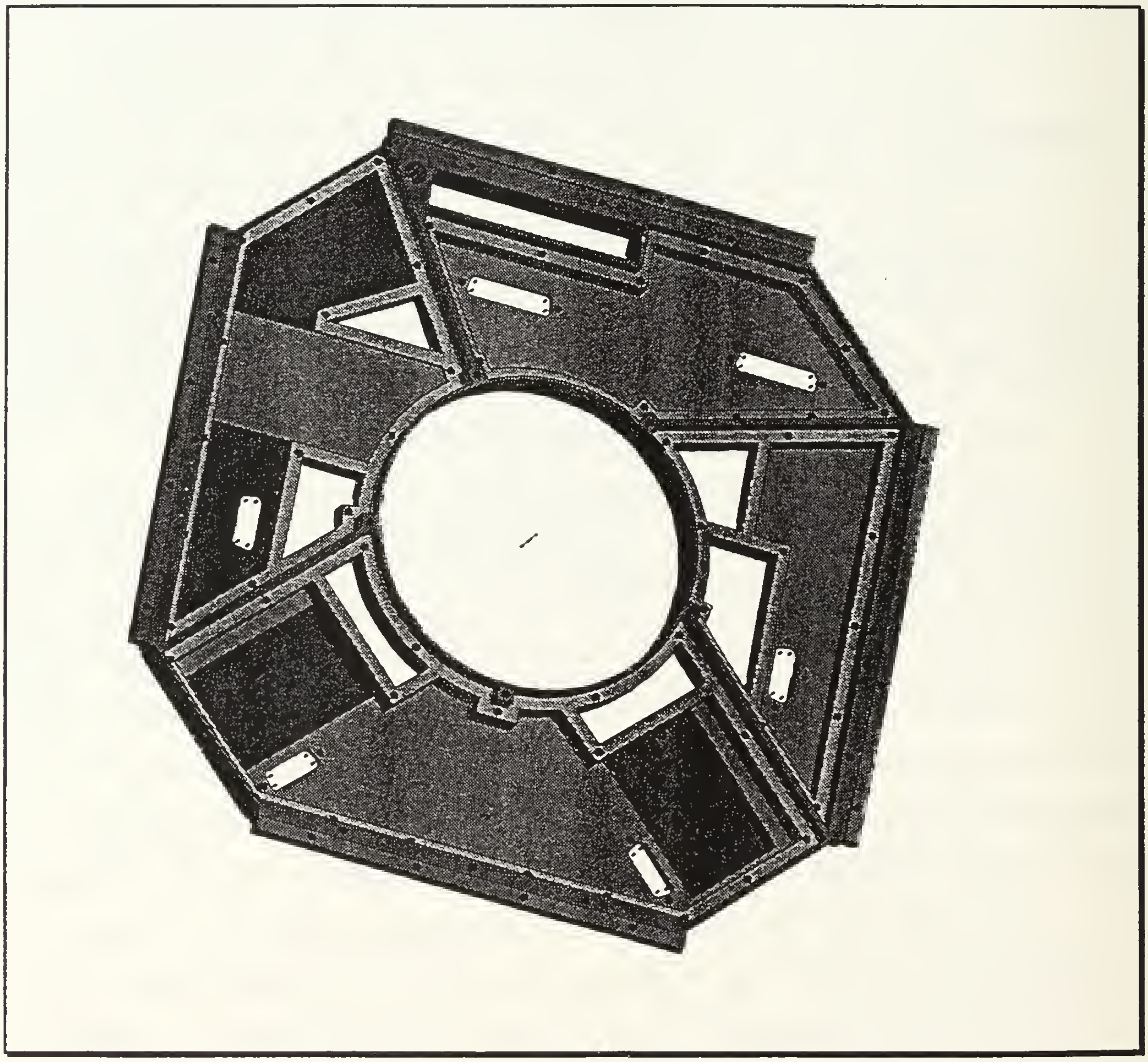


Figure 4. RF Housing

2. Lid

A lid is added to provide enough EMI shielding between the boards. Three tunnels, each 0.1 inches thick and 0.2375 inches long, protect the SMA-Connectors (coaxial cables) and a 25-PIN-Connector. It also supports two connectors that connect parts below and above the housing (see Chapter C.1.)).

For the most part, the lid is only 0.065 inches thick, which is more than sufficient to provide enough stiffness (see results), but nearly too thin concerning manufacturability. A lot of caution will have to be taken in milling this because an increase in temperature could cause bending or small fractures. Since the main task is EMI shielding the lid has to fit perfectly between the housing and the equipment plate.

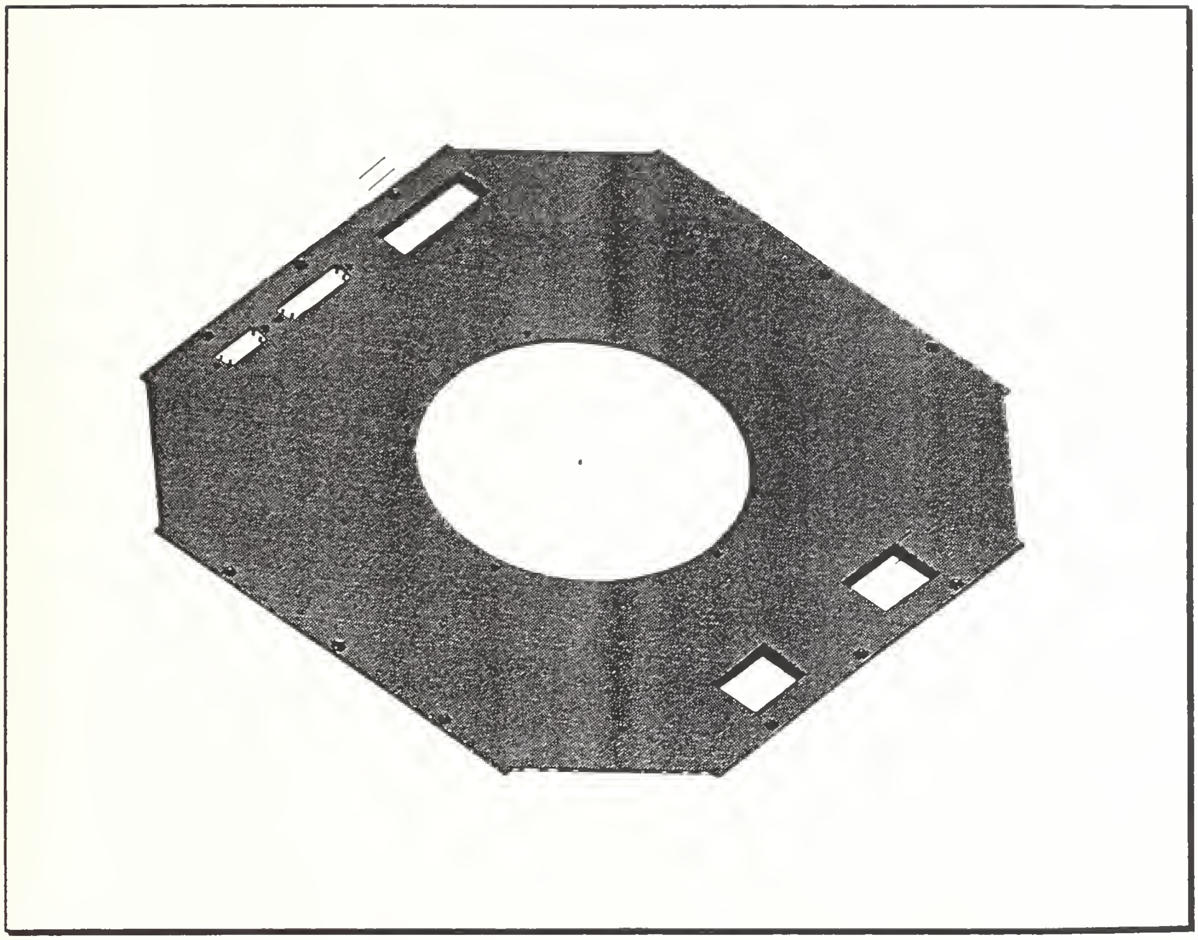


Figure 5. RF Lid

3. RF Board

The RF board is the biggest circuit of the four boards and will be mounted in pocket "E"(Appendix C). As with the other boards, the components will be located upside down between the board and the bottom of the housing. The largest components are the two oscillators. Two pockets were designed (2 x 3 x 1.165 inches) to surround them producing natural shielding as well as providing enough space. The location of the connector cutout as well as the mounting holes of the boards to the housing have to be as precise as possible or problems might occur when fitting the parts. The RF Switching Schematic (Appendix D) shows all components being attached to the board.

4. HPA Board

The HPA board houses two high power amplifiers (Appendix D / HPA Schematic) that will be located between the board and the elevation in the middle of pocket "G". The gap of 0.07 inches has to be precise. The location of the connector cutout near may be varied as long as the location of the filter for the antenna is considered and does not interfere.

5. LNA Board

Pocket "F" houses the smallest board within the RF housing. The PC board consists of only three components (Appendix D / LNA Schematic). Under it the antenna relay will be located because the cable going from C7 (Fig. 7) to the relay has to be as short as possible. Every added length causes more noise. Therefore the connector cutout can only be changed, very little.

6. POWER Board

Changes of the shape of this PC board are very probable because the design of the switching schematic has not yet been completed. The antenna filter will be mounted below this board which dictates the locations of the two connector out cuts.

C. ASSEMBLY

The four boards must be attached to the housing, and the housing as a whole must be attached to the lower equipment plate. Screws are used for this purpose. The screws had one of the largest impacts on the dimensions of the housing. Edges 0.25 inches wide had to be made to support the circuit boards and walls had to be made thicker than structurally required in order to provide space for the screws to be inserted with enough room on either side of the screws to maintain structural integrity. 4-40-screws are used throughout the structure. 4-40-flat-head-screws are used to fix the lid to the housing and 4-40-socket-head-screws are used to attach the boards to the housing as well as the housing to the lower equipment platform. The 4-40-screws have a 0.112 inch shaft diameter with 40 threads per inch. Socket heads were selected because they are easier to work with when loosened or tightened. The flat-head-screws are needed because the lid is located between housing and equipment plate where only a gap of 0.065 inches is available. All holes, except the ones where the lid is mounted to the housing, are through holes. But all have an opening to the top as well as to the bottom so that any material loosened by the screw as it is inserted can fall through and there are no blind holes which volume might cause trouble under vacuum conditions, when expanding in lower pressure conditions. The boards and the lid will be joined to the housing before the housing is attached to the lower equipment plate. The screws fastening the lid and the boards to the housing will end up in locking helical coils 0.145x0.168 inches big. The outer screws attaching the housing to the equipment plate will counter bore into the equipment plate

(0.15 inches deep and 0.225 inches in diameter) with split washers (0.209x0.031 inches) and end in locking helical coils in the housing 0.145x0.168 inches (Fig. 6). The interior screws (5) are one inch long, counter bored into the RF housing (0.14 inches deep and 0.225 inches in diameter) with split washers added to them and end in locking helical coils (0.145x0.224 inches) in the equipment plate leaving at least 0.066 inches to the top of the equipment plate. This is required so that the DCS housing does not interfere with the tip of the screws. Split washers are used to keep the diameter of the counter bores and edges as small as possible. Other washers could have caused interference problems with other holes or parts.

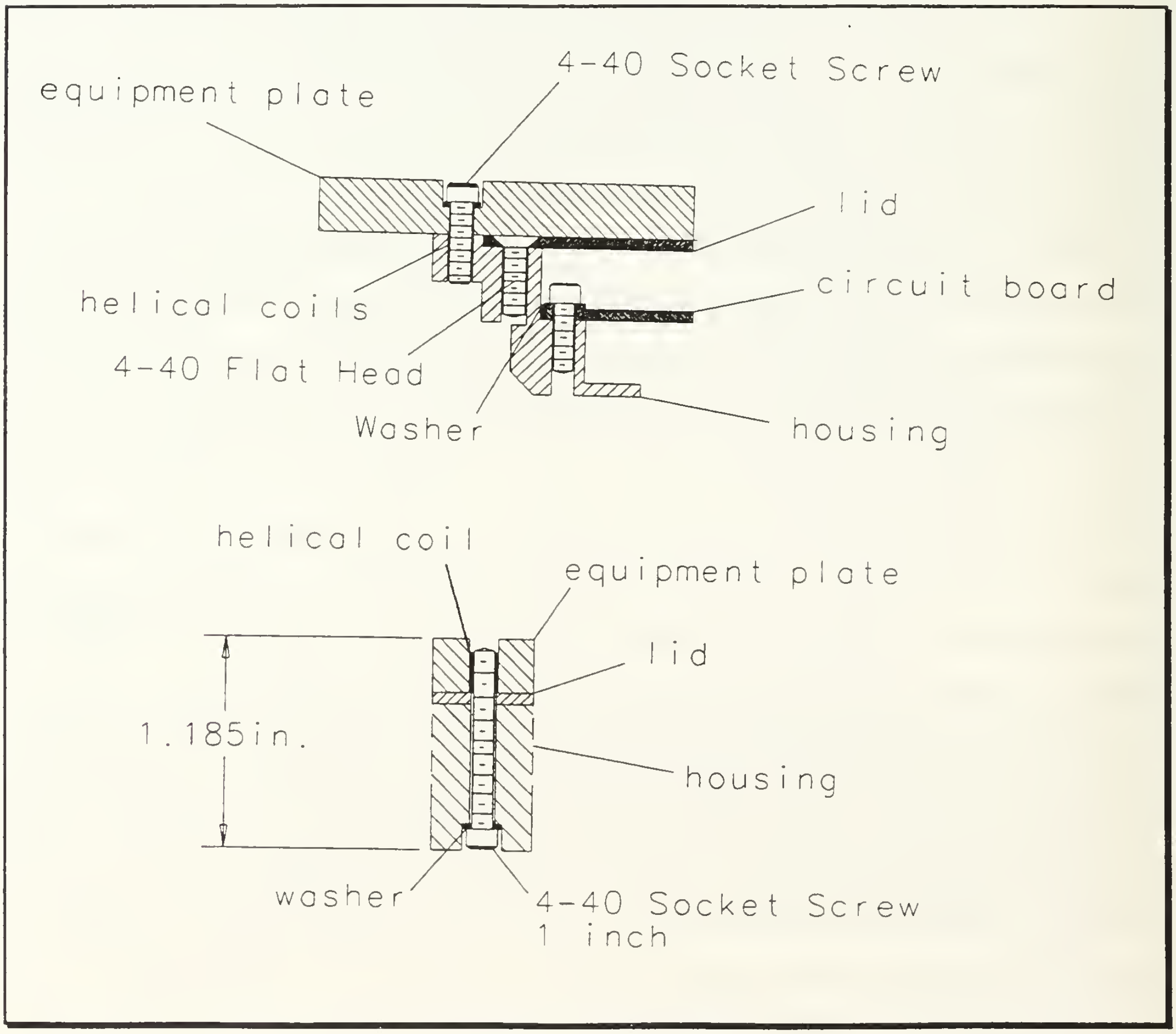


Figure 6. Attachments

The following screws, helical coils and washers will be needed to join the boards, the lid, the housing and the equipment plate:

Amount	Screw / Helical Coil / Washer Type	Length (inches)
12	4-40/82` Flat Head (mounting the lid to the housing)	0.375
55	4-40 Socket Head (mounting the boards to the housing)	0.375
16	4-40 Socket Head (mounting the housing to the equipment plate)	0.5
5	4-40 Socket Head (mounting the housing to the equipment plate)	1.0
83	1.5 DIA helical coils	0.145 x 0.168
5	2 DIA helical coils (for the 1-inch-screws)	0.145 x 0.224
88	Split washer	0.209 x 0.031

Table 2. Screws, Helical Coils and Washers

Assembling the parts in the end

After all housings are ready to be joined, the following "mounting order" is recommended for the lower part of PANSAT:

- attach the RF housing to the lower equipment plate (LEP)
- mount the cylinder support to the LEP
- attach the DCS and the Battery housings to the LEP → block 1
- join all parts under the LEP (except the cylinder support and the RF housing) → block 2
- join block 1 and block 2

The main problem will be that block 1 and block 2 are both having wires attached to "P8" (Fig.8); therefore, working with spacers will be necessary.

1. CABLES AND CONNECTORS

Instead of having hundreds of wires connecting the boards in a confusing way, **connectors** are being used to make the joining easier as well as to minimize the danger of wires being damaged or accidentally miss connected.

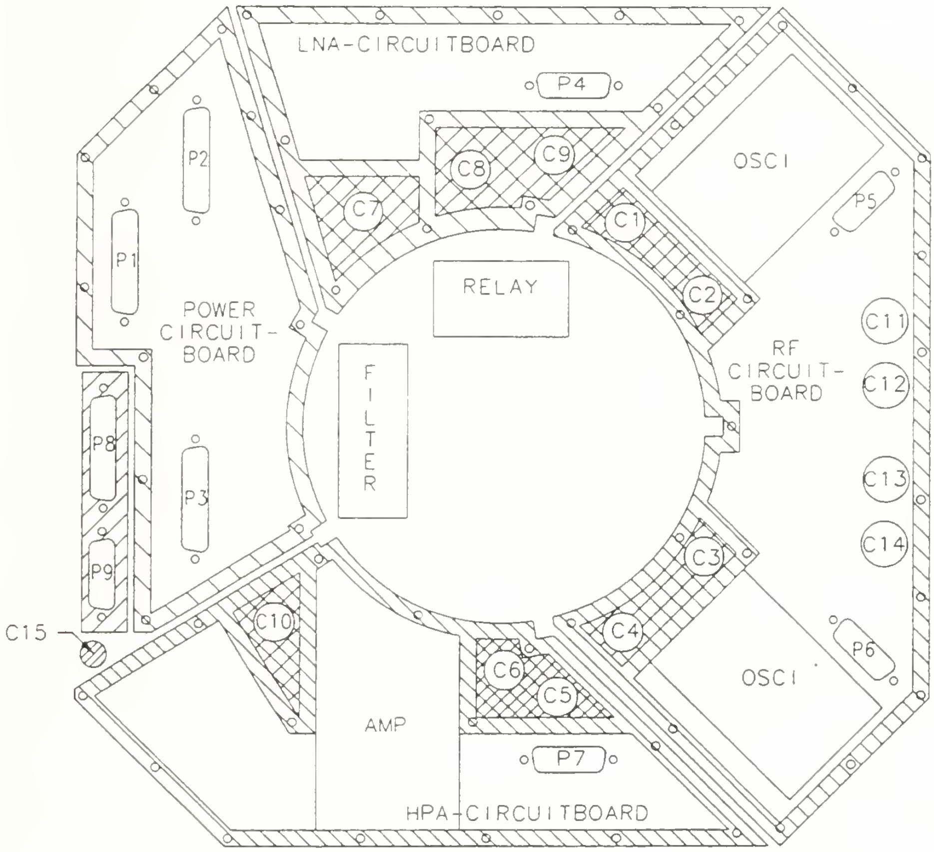


Figure 7. Connection Schematic

P1 is a 25-pin-connector mounted at the POWER circuit board. It supplies the RF housing with power and enters the housing through an opening in the equipment plate and the lid. The lid provides additional EMI shielding by a 0.1 inch thick wall surrounding the connector.

P2 and P3 are both 25-pin-connectors connecting the POWER circuit board with the other boards and are mounted at the bottom of the RF housing.

P4, P5, P6 and P7 are 15-pin-connectors mounted to the bottom of the RF housing and originate in P3 or P2, except for the temperature sensor wires which go to P8.

P8 and P9 are mounted to the lid of the RF housing and are not attached to any of the circuit boards directly. **P8** is a 44HD-pin-connector which connects 30 wires coming from underneath the lower equipment plate to the upper part of the satellite, as following:

- 10 wires are coming from the temperature sensors of the five solar panels (two each) underneath the RF housing
- 16 wires are coming from the temperature sensors of the RF housing; (probably) 5 from the RF-board, 3 from the POWER-board and 4 each from the LNA- and HPA-boards.
- 4 wires are coming from the RF housing (analog)

P9 is a 26HD-pin-connector which connects 24 wires. These 24 wires include:

- 4 wires from the microswitches
- 20 wires from the five solar panels(2 each for power and 2 each for return) located in the bottom section of PANSAT

C1-C14 are coaxial cable connectors mounted to the electrical boards. The RF housing provides EMI shielding by "tunnels" that surround the cable connections and touch the boards - an EMI gasket is not needed because the .25 inches wide metal surface touching the boards provides enough shielding. The advantage of the design shown in figure 7 is that assembly and testing are a lot easier compared to a connection through the walls or the top, plus additional shielding and stiffness is provided.

C1 and **C2** connect with **C8** and **C9**, **C3** and **C4** lead to **C5** and **C6**.

C7, C10 and C15 all provide the direct attachment of the antenna.

The antenna cable will be mainly located in the top of PANSAT and then goes through the RF housing (**C15**) and ends in a filter which will be located under the POWER-board, from where a cable goes to a relay mounted under the LNA-board. This is necessary because the connection between the relay and LNA (**C7**) has to be as short as possible to minimize the noise. Another cable connecting the relay with the HPA-board ends in **C10**.

C11-C14 connect the RF circuit board with the Digital Control System (DCS) and are shielded by the lid of the housing.

The maximum size of the **FILTER** will be **6.5x2x1.3 inch**. The final size will be determined after functional testing. A position between the support cylinder and P3 and P2 is recommended.

The **RELAY** should be mounted under the LNA-board. Its biggest dimensions are **2x1,4x1,4 inch** and will easily fit between the out cut of C7 and the the solar panel.

III. FINITE ELEMENT ANALYSIS

A. MODELING THE DESIGN

With the advent of the digital computer it is now possible to model structures mathematically in great detail, and to examine their behavior under all possible load conditions, static or dynamic. The essence of the finite element analysis (FEA) method is to divide the structure into a large number of discrete elements, within each of which the load distributions, elastic properties and boundary conditions are known. For each element appropriate parameters can be fed into the computer describing material properties, shape, degrees of freedom and connection to the next element. The computer program enables the structure to be evaluated under static loads. It is also possible to conduct a dynamic study (i.e. under fluctuating loads). In a dynamic simulation natural frequencies can be assessed and relative phase information of deflection shapes at different locations within the structure can be indicated.

A finite element analyses was performed using the SDRC I-DEAS finite element application. The process involves the utilization of modules to perform certain tasks in the progress of the analysis. Process modules are defined as “ Tasks” in the IDEAS nomenclature. The process flow for the I-DEAS FEA software is shown in figure 8. The finite element modeling are provided in the following tasks. [Ref. 5,6]

- Geometry Modeling: creates the geometry of the structure (points, lines, surfaces) without any material properties
- Beam Section Modeling: creates the cross section of beam elements and derives/modifies the properties
- Mesh Creation: creates nodes and elements; defines material properties and physical properties; defines and generates element meshes; and performs quality checks for coincident nodes and elements
- Boundary Conditions: defines case sets and creates restraint sets and load sets

- Model Solution: defines type of analysis, case sets used, and solution parameters to create data analysis sets
- Post-Processing: chooses data analysis sets; displays deformed geometry, stress contours, and animation of mode shapes; manipulates data analysis sets to create combined loads

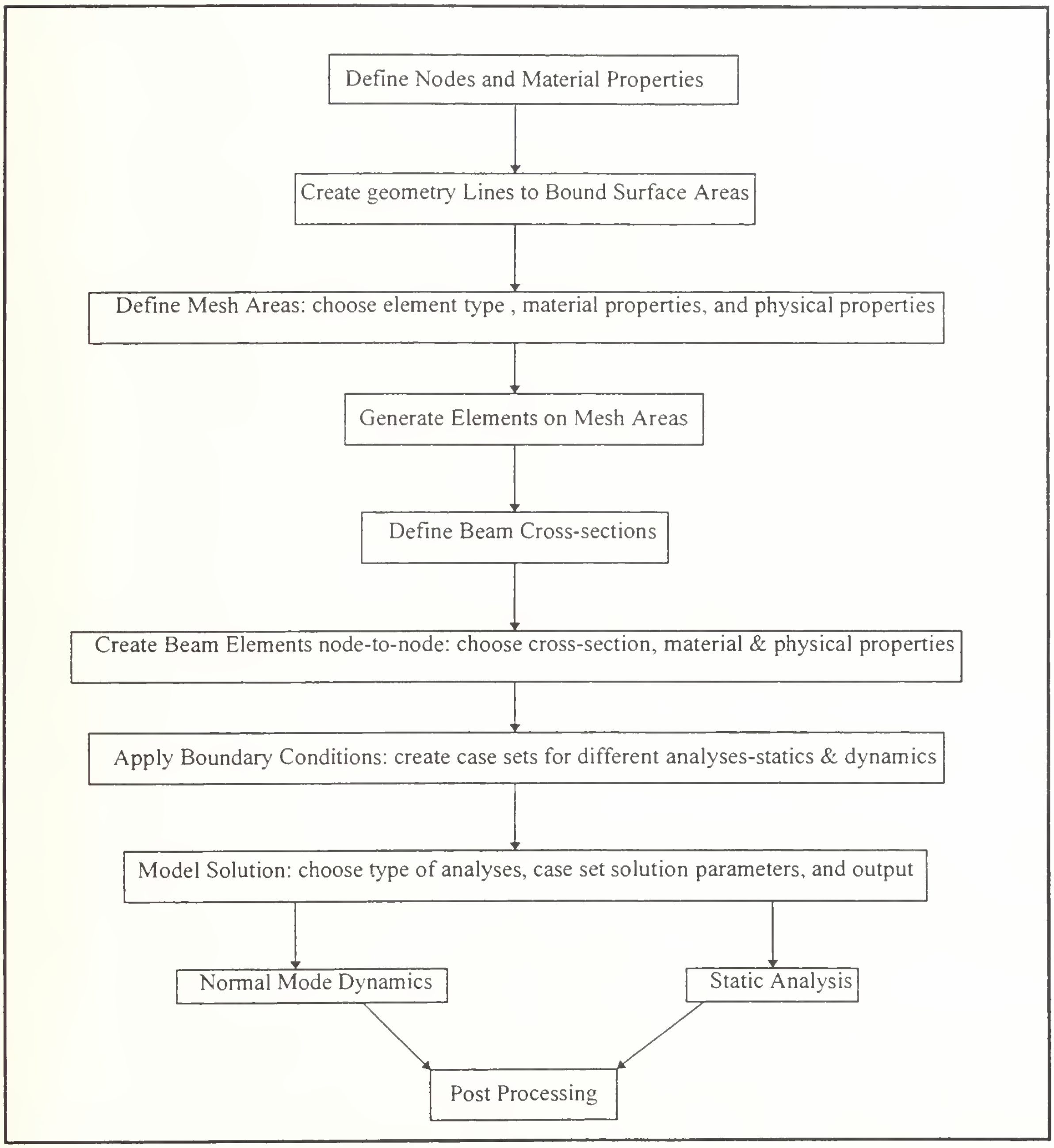


Figure 8 : I-DEAS FEA Process Flow

B. FINITE ELEMENT ANALYSIS RESULTS

1. STATIC ANALYSIS RESULTS

Finite element analysis results show that the structure is capable of withstanding the loads of a shuttle launch.

For the main housing a model of thin shell elements, each .0625 inch thick and 0.7 inch wide, was created, with four surfaces simulating the pockets for the four boards , surrounded by beam cross sections 0.125 inches wide and 0.8 inches high. This size of the elements was chosen because this mesh structure gave results in a reasonable time. The number of nodes and elements of each part is listed in table 3. Lumped mass elements, weighing 0.1 to 0.25 lbs, were added simulating the components added to the parts. After generating the meshing and adding the lumped mass elements (located at nodes in the given mesh structure simulating the components), a boundary set was created. At the locations where the housing will be mounted to the lower equipment platform and where the boards and the lid are fixed to the housing, restraints were set in form of clamps, giving particular nodes no degree of freedom.

Part	Mass , lb.	nodes	elements
main box	3.4	358	314
lid	0.9	351	303
LNA	.5	87	69
RF	1	154	127
HPA	.5	107	86
POWER	.75	92	72

Table 3. I-DEAS DATA

A linear static solution set was done for each case, using the models and boundary conditions described. A load set was created simulating an acceleration of 56 g's (40x1.4)

in X-direction and 28 g's (20x1.4) in Y-, as well as Z- direction (Fig. 9). This will be the main stress forces which the housing and its payload will have to withstand.

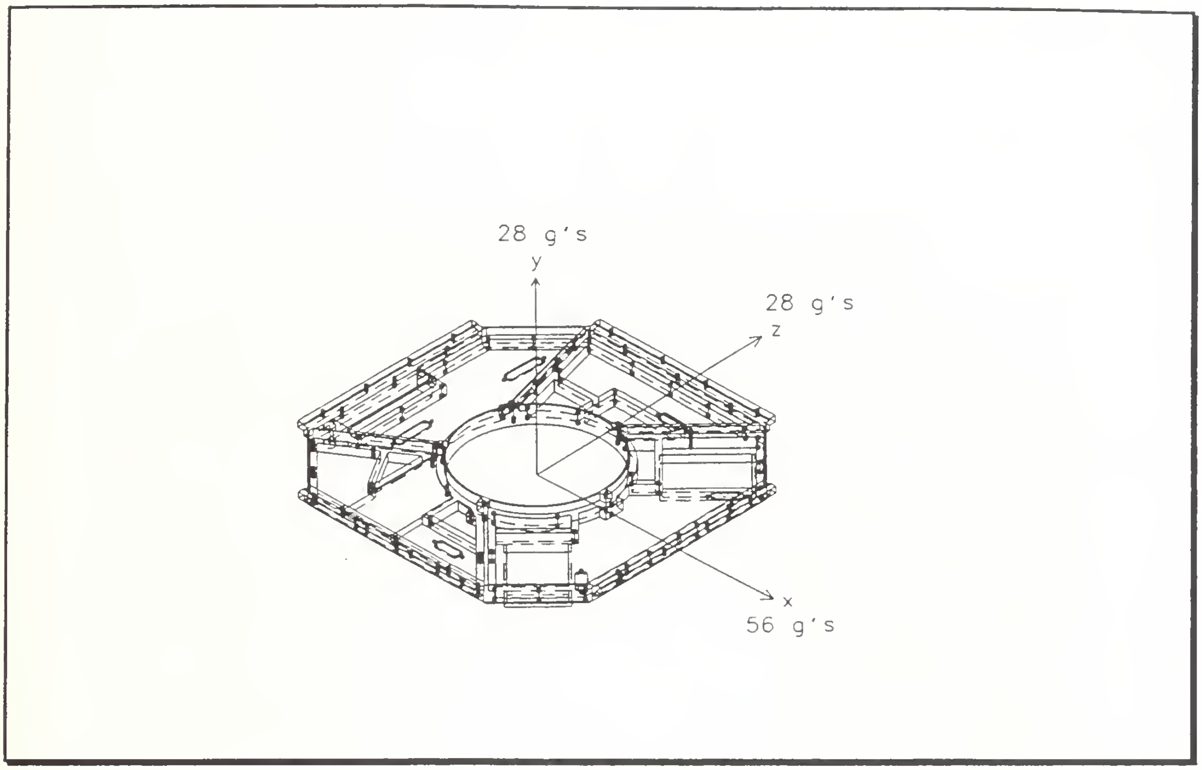


Figure 9. Acceleration Forces

Shear Stress

Von Mises, or maximum octahedral shear stress, failure criterion was used to determine the margins of safety for all structural elements. The biggest von Mises stress occurred for the combined load case of the housing. The result was 6.59 psi and the model is shown on the next page in Fig. 10. The results for the boards and the lid were up to six times less. This is much lower than the 36,000 psi yield stress value for aluminum 6062-T6.

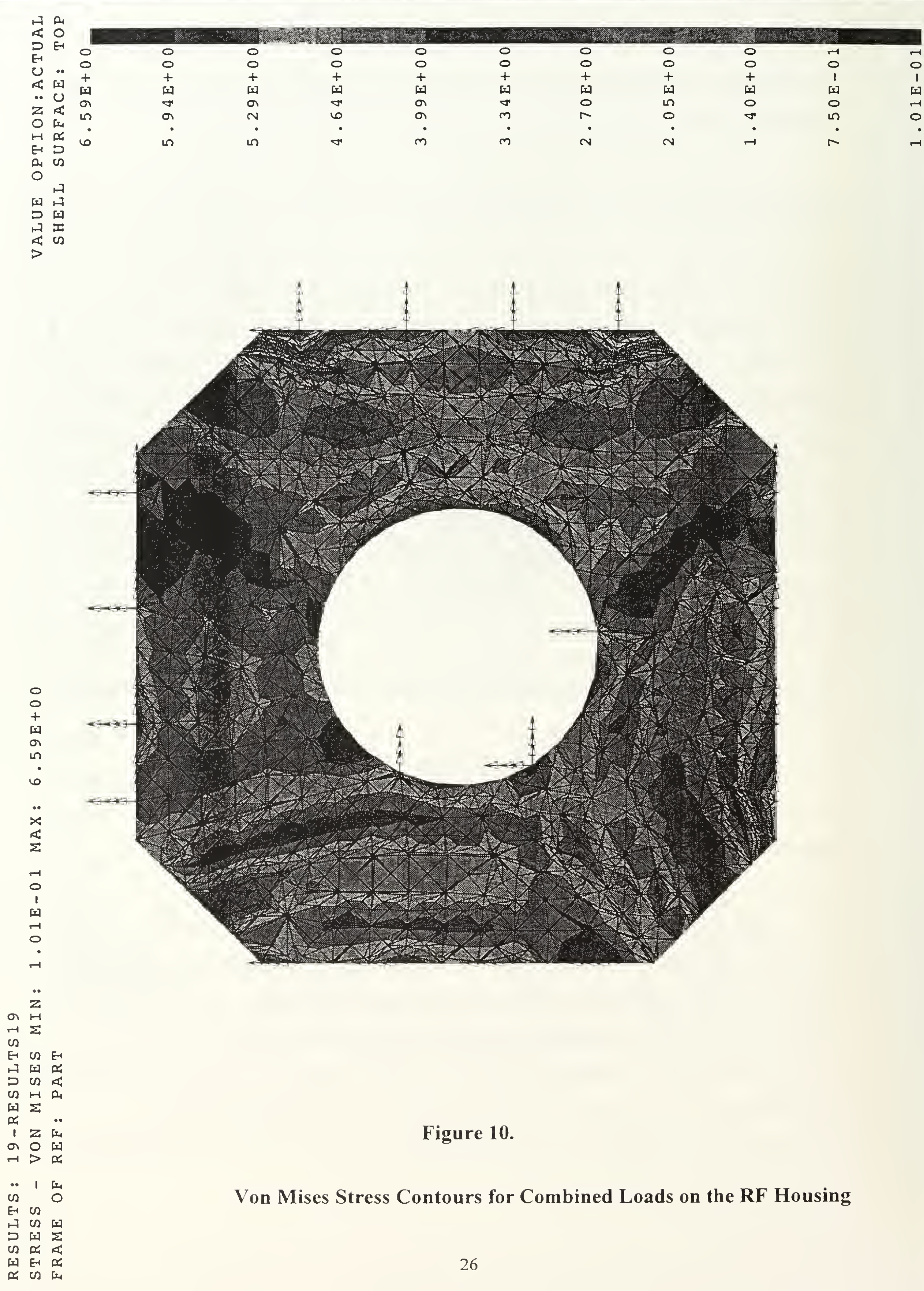


Figure 10.

Von Mises Stress Contours for Combined Loads on the RF Housing

2. DYNAMIC ANALYSIS RESULTS

Natural frequency

The RF circuit boards are populated with several components. Electrical lead wires connect the components to the board. These wires are very thin and if broken will disrupt the flow of power and information, possibly causing spacecraft failure. The intense loads placed on the satellite during the launch environment will cause the circuit boards to vibrate, producing bending stresses in the electrical leads. If these stresses are high enough, the wires will break.

Whether or not the wires break is a function of several factors, including board weight, component size, launch loads, how and where the components are mounted to the board, how long the vibrations last, what type of strain relief the lead wires have and the natural frequency of the board. These factors all have their most severe effect during resonant conditions; therefore the examination of the natural frequency is of major importance.

Before starting an IDEAS run with the FEA model a quick evaluation is being made considering the natural frequency. This can be approximated using the Rayleigh method [Ref. 4]. A "worst case" of a rectangular plate, 7 x 7 inches was chosen, fixed along all four edges and maximum displacement in the center (7 inches is about the distance between the center and the edge of the RF housing).

The natural frequency is:

$$f_n = \frac{1.96}{\pi}\left[\frac{D \cdot 5.02}{\rho \cdot a^4}\right]^{\frac{1}{2}} = \mathbf{232.93\ Hz}$$

a = board length / width , 14 in.

$$\rho = \frac{mass}{area} = \frac{4.0}{g \cdot a^2} = \frac{4}{386 \cdot 7^2} = 5.29 \text{ x } 10 \text{ E-04 lb. sec}^2/\text{in.}^3$$

$$D = \frac{Eh^3}{12\left(1-\mu^2\right)}$$ (plate stiffness factor)

E = modulus of elasticity, 9.9×10^6 psi

h = plate thickness, 0.065 in

μ = Poisson's ratio, dimensionless , 0.3

Therefore the worst case is nearly five times the frequency required (50 Hz); see Chapter II.A.1.

The deflection will be a maximum at the center and is given by

$$\delta_r = 9.8 * G_{in} * Q / f_n^2 = 0.046 \text{ in.}$$

where:

δ_r = deflection (in inches)

G_{in} = peak input accelaration (12*1.4)

Q = $K\sqrt{f_n}$ = transmissibility

f_n = natural frequency [Ref.4].

Q is related to the square root of the natural frequency of the board. The term 'K'in the equation above for Q represents this relationship. K generally varies between 0.5 and 2.0 (here 1). The value for transmissibility, Q, is approximated, since an exact value for K is difficult to come by without actual test data on the design under consideration.

In general finite element analysis will give better answers. With nodes and elements, the specific shape can be simulated more precisly. Each model was analyzed with boundary conditions with all sides clamped at the knodes where the boards and the lid are fixed to the housing and the housing is mounted to the lower equipment plate. Then a dynamic solution set was done for each part. The results are shown in table 4 (frequency / structure alone). A new model was then generated, using the same meshing, but adding lumped mass elements weighing 0.1 or 0.25 lbs and located where the components could will be placed. Another solution set was done, using the same boundary conditions as in the first. Since the lowest natural frequency is of interest, only the second solution set was generated with the boards. The lid only passed the first solution set because obviously no masses will be added to it.

All model results are shown in appendix E.

Part	Frequency , Hz (structure alone)	Frequency , Hz (mass added)
main box	780.82	385.88
lid	370.90	
LNA circuitboard		350.65
RF circuitboard		267.13
HPA circuitboard		382.91
POWER circuitboard		334.98

Table 4. I-DEAS Modal Summary

The simulated result shows that the construction itself is more than capable of withstanding all forces arising during the lifetime of PANSAT.

IV. CONCLUSION

I-DEAS software was used to develop a design for the PANSAT RF housing and circuit boards. The software was also used to generate finite element models and analyze them for structural integrity. The results indicate that the design easily met the requirements set forth by the Hitchhiker program for stress and natural frequency.
The design has been developed only using software simulation. To ensure the design does meet the requirements, testing of the hardware is strongly recommended.

All layouts are current as of September 1995 and the present design is a prototype. The size of all boards except the RF board, as well as the location of the connectors, have to be confirmed until the electrical layout, performed by Carl Lathi, is finished. Small changes are possible.

EMI was discussed in detail in Chapter III.A. As mentioned, only actual testing will ensure if EMI problems do exist. The design allows only minimal adding of additional shielding. Therefore, negative test results could necessitate a new design.

A thermal analysis was not performed due to the lack of data concerning the temperatures of the components. This aspect should be considered when accurate data becomes available.

A very robust design has been developed for the RF housing and the circuit boards. The analysis shows that the design will exeed the requirements mandated by the Hitchhiker program. To ensure these requirements are met, the next logical step is to manufacture the part and proceed with testing.

APPENDIX A

BUCKELING STRESS SAFETY MARGIN

A panel of 14 x 14 inches is analyzed assuming a worst-case compression load of the structure weight at 40 g's (4 lbf x 40 g's), and a moment acting at 14 inches (maximum width of the housing) from the launch vehicle interface at 20 g's (4 lbf x 14in. x 20 g's). Torsion is considered negligible.

ALUMINUM 6061-T6 ANALYSIS PARAMETER

Young's Modulus, E	Compressive Load	Moment
9.9 x 106 psi	160 lbf	1120 in-lb

Thickness, t = 0.0625 in. Width, w = 14 in.

The analysis for the panel for the combined load of axial compression and bending follows.

The buckling stress allowed for the design of a panel under axial load is given by [Ref.9]:

$$\sigma_{cr} = C_c\left(\frac{Et}{w}\right)$$

where, Cc = buckling stress coefficient

t = thickness

w = width

Cc is given as 0.15 from empirical results for clamped edges.

The stress ratio for axial compression is

$$R_c = \frac{P}{\sigma_{cr}} = 0.02$$

and for bending

$$R_b = \frac{M}{\sigma_{cr}} = 0.1515$$

The margin of safety for the combined load is gives as $\frac{1}{R_c + R_b} - 1 = 4.18$ or 418 %.

The structure could be made thinner, but this would cause problems manufacturing the part.

APPENDIX B

CG AND INERTIA POINT

f the RF housing and the RF lid without considering the load of the circuitboards: the following coordinates were taken as reference:

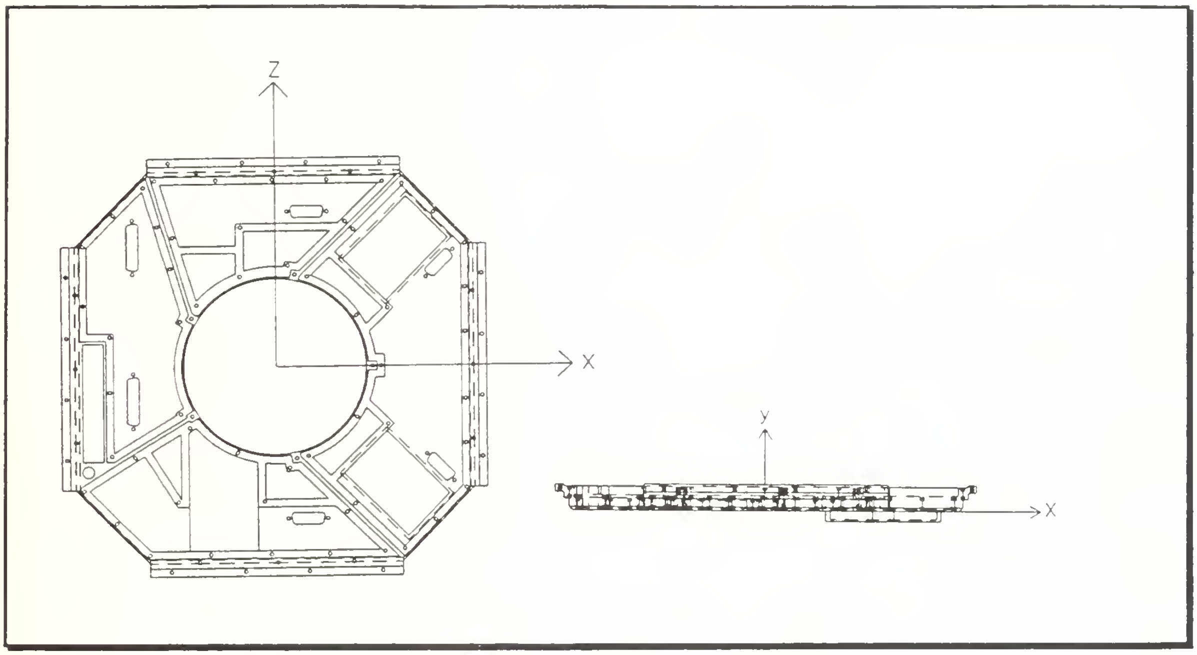


Figure 11. Coordinate System

RF HOUSING

Solid surface area: $452\ in^2$

Volume : $36.7\ in^3$

Mass : 3.56 lb.

Center of gravity:

CG X : -0.19 in

CG Y	:	4.43 in
CG Z	:	0.13 in

Inertia Point	: Local center of gravity	
Ixx	:	0.17
yy	:	0.32
Izz	:	0.15
Ixy	:	-0.001
Iyz	:	-0.0003
Ixz	:	-0.004

RF LID

Solid surface area:		$283in^2$
Volume	:	$9.14\ in^3$
Mass	:	0.90 lb.

Center of gravity:

CG X	:	0.06 in
CG Y	:	4.98 in
CG Z	:	-0.02 in

Inertia Point	: Local center of gravity	
Ixx	:	0.04
Iyy	:	0.07
Izz	:	0.03
Ixy	:	0.00
Iyz	:	0.00
Ixz	:	0.00

APPENDIX C

MECHANICAL DRAWINGS

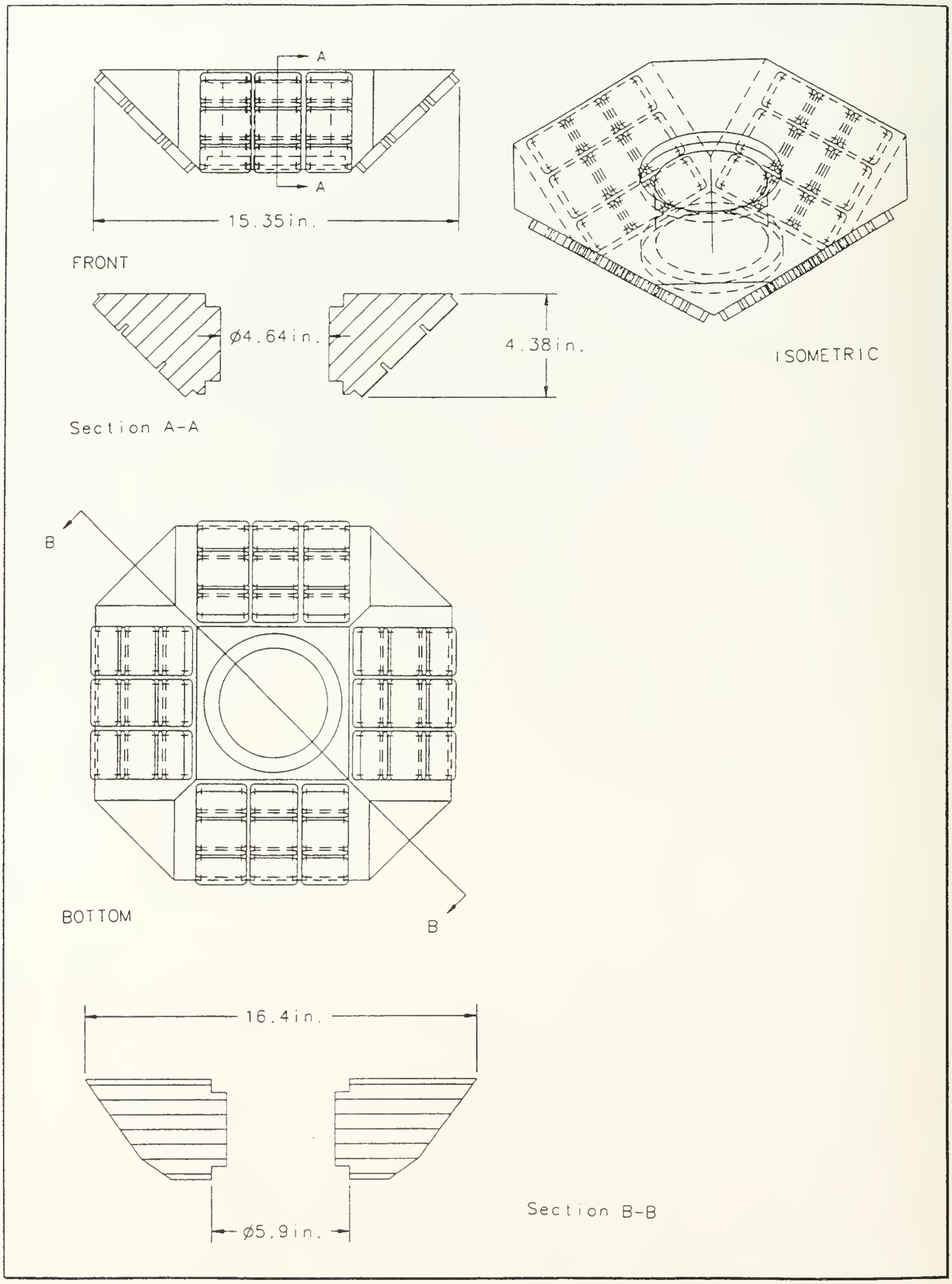
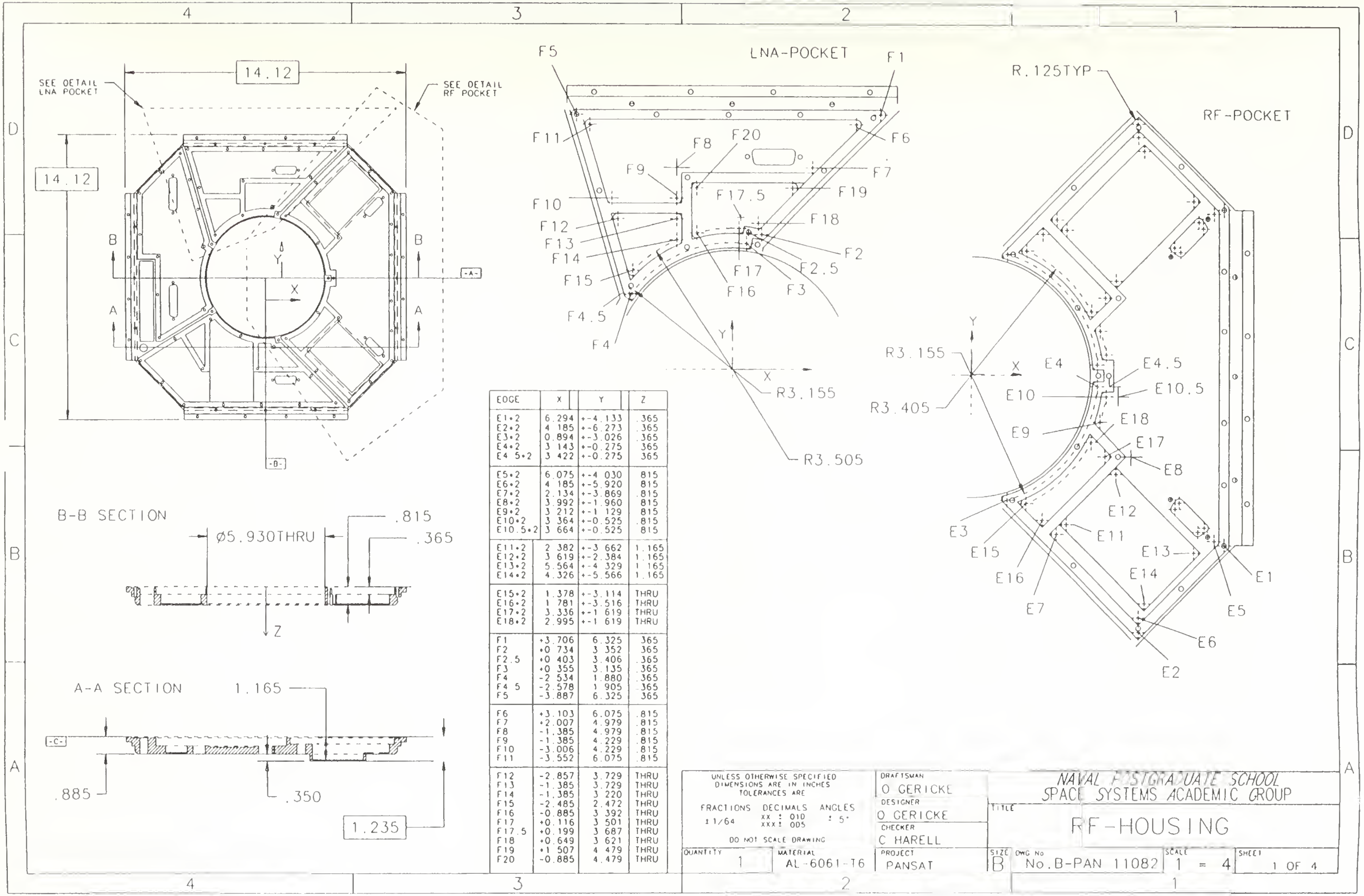
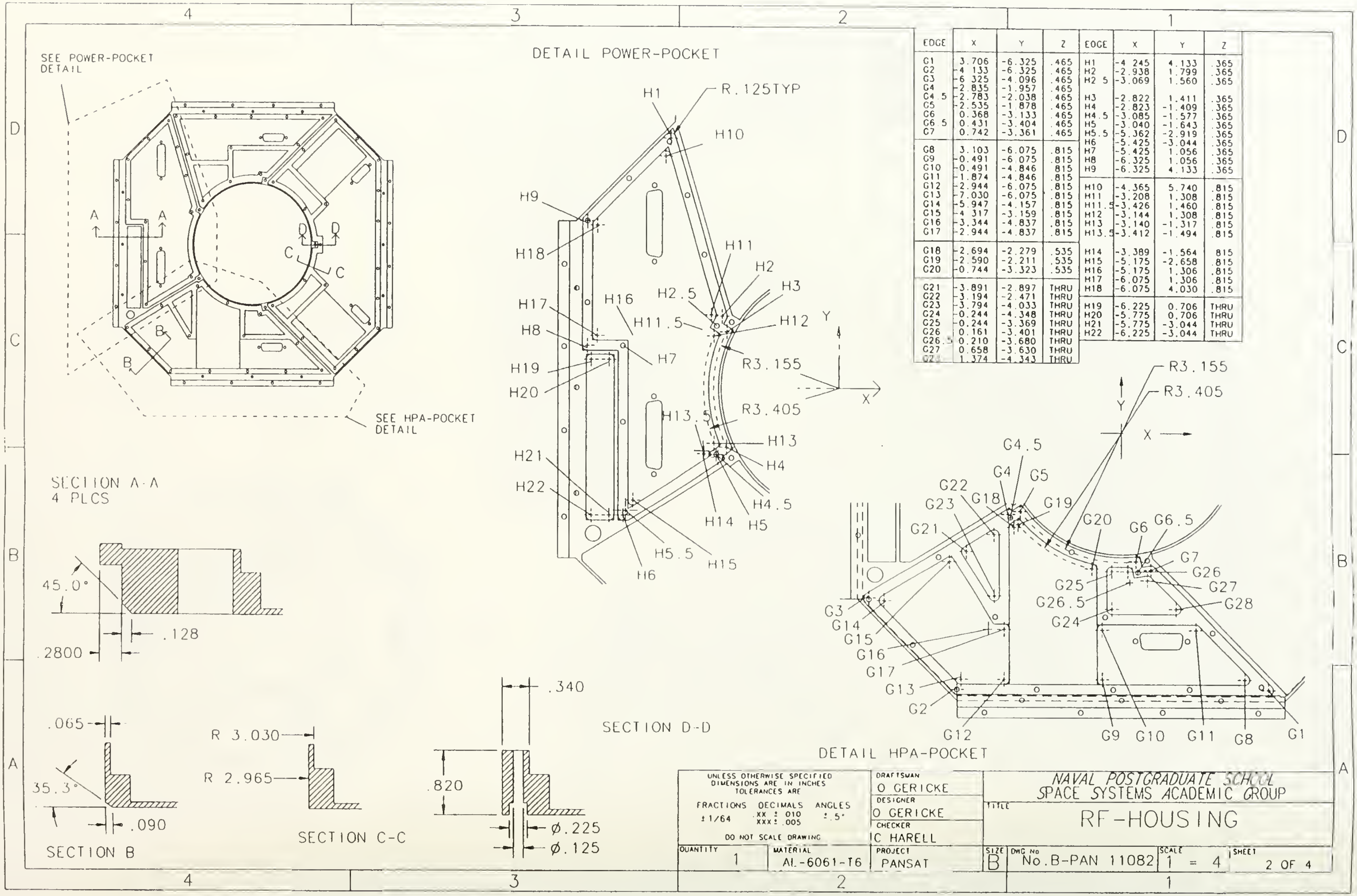


Figure 12. Envelope of the RF Housing



EDGE	X	Y	Z
E1•2	6.294	+-4.133	.365
E2•2	4 185	+-6.273	.365
E3•2	0.894	+-3.026	.365
E4•2	3 143	+-0.275	365
E4 5•2	3 422	+-0.275	365
E5•2	6.075	+-4 030	815
E6•2	4 185	+-5.920	815
E7•2	2.134	+-3.869	.815
E8•2	3.992	+-1.960	815
E9•2	3 212	+-1 129	815
E10•2	3 364	+-0.525	.815
E10.5•2	3 664	+-0.525	815
E11•2	2 382	+-3 662	1.165
E12•2	3 619	+-2.384	1.165
E13•2	5.564	+-4 329	1 165
E14•2	4.326	+-5.566	1.165
E15•2	1.378	+-3.114	THRU
E16•2	1 781	+-3.516	THRU
E17•2	3.336	+-1 619	THRU
E18•2	2.995	+-1 619	THRU
F1	+3.706	6.325	365
F2	+0 734	3 352	365
F2.5	+0 403	3.406	.365
F3	+0 355	3.135	.365
F4	-2 534	1.880	.365
F4 5	-2.578	1 905	.365
F5	-3.887	6.325	365
F6	+3.103	6.075	.815
F7	+2.007	4.979	.815
F8	-1.385	4.979	.815
F9	-1.385	4.229	.815
F10	-3.006	4.229	.815
F11	-3.552	6.075	.815
F12	-2.857	3.729	THRU
F13	-1.385	3.729	THRU
F14	-1.385	3 220	THRU
F15	-2.485	2.472	THRU
F16	-0.885	3 392	THRU
F17	+0.116	3 501	THRU
F17.5	+0.199	3 687	THRU
F18	+0.649	3 621	THRU
F19	+1 507	4 479	THRU
F20	-0.885	4.479	THRU

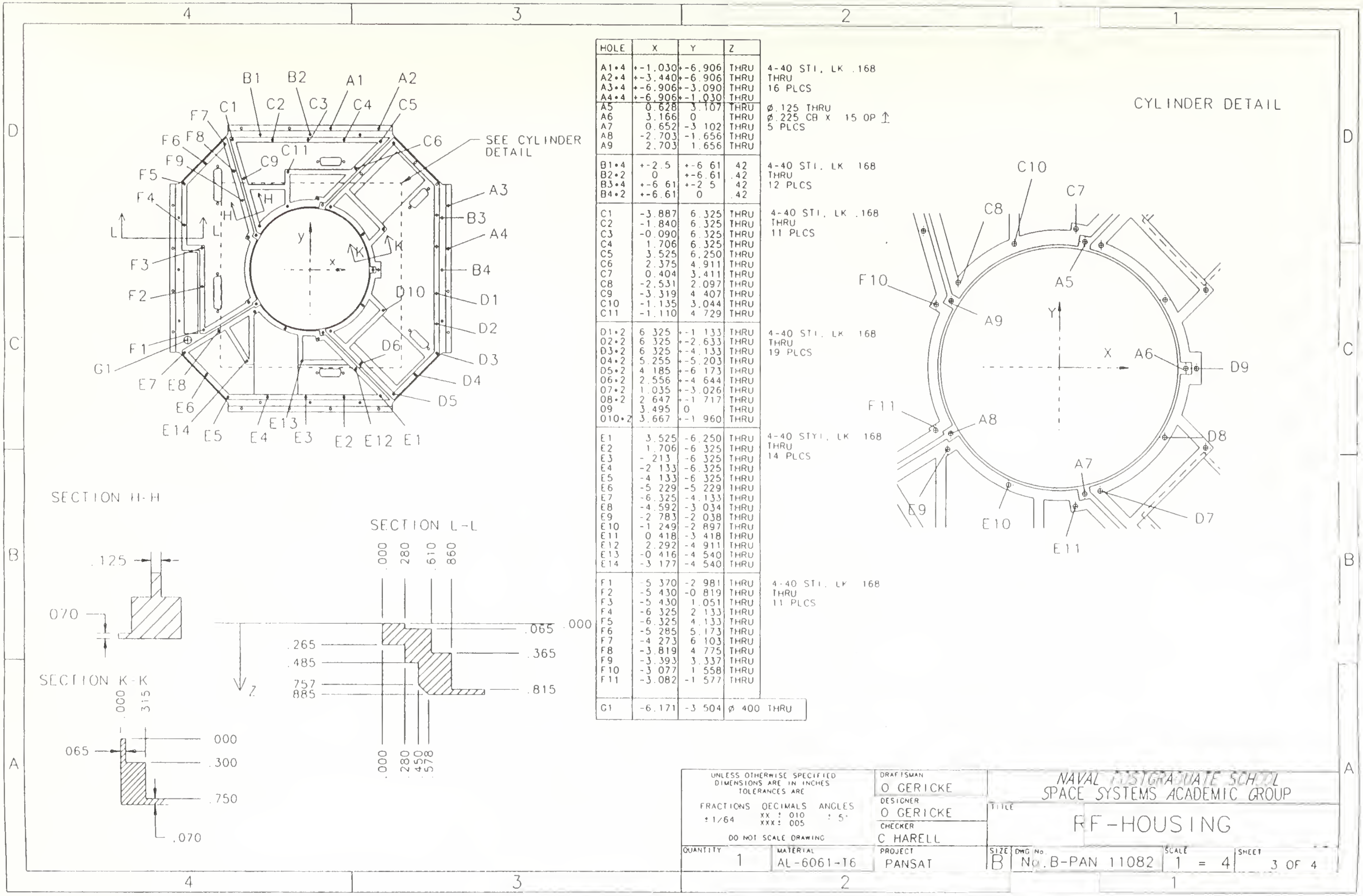
Figure 13 RF Housing Nr. 1



EDGE	X	Y	Z
G1	3.706	-6.325	.465
G2	-4.133	-6.325	.465
G3	-6.325	-4.096	.465
G4	-2.835	-1.957	.465
G4.5	-2.783	-2.038	.465
G5	-2.535	-1.878	.465
G6	0.368	-3.133	.465
G6.5	0.431	-3.404	.465
G7	0.742	-3.361	.465
G8	3.103	-6.075	.815
G9	-0.491	-6.075	.815
G10	-0.491	-4.846	.815
G11	-1.874	-4.846	.815
G12	-2.944	-6.075	.815
G13	-7.030	-6.075	.815
G14	-5.947	-4.157	.815
G15	-4.317	-3.159	.815
G16	-3.344	-4.837	.815
G17	-2.944	-4.837	.815
G18	-2.694	-2.279	.535
G19	-2.590	-2.211	.535
G20	-0.744	-3.323	.535
G21	-3.891	-2.897	THRU
G22	-3.194	-2.471	THRU
G23	-3.794	-4.033	THRU
G24	-0.244	-4.348	THRU
G25	-0.244	-3.369	THRU
G26	0.161	-3.401	THRU
G26.5	0.210	-3.680	THRU
G27	0.658	-3.630	THRU
G28	1.374	-4.343	THRU

EDGE	X	Y	Z
H1	-4.245	4.133	.365
H2	-2.938	1.799	.365
H2.5	-3.069	1.560	.365
H3	-2.822	1.411	.365
H4	-2.823	-1.409	.365
H4.5	-3.085	-1.577	.365
H5	-3.040	-1.643	.365
H5.5	-5.362	-2.919	.365
H6	-5.425	-3.044	.365
H7	-5.425	1.056	.365
H8	-6.325	1.056	.365
H9	-6.325	4.133	.365
H10	-4.365	5.740	.815
H11	-3.208	1.308	.815
H11.5	-3.426	1.460	.815
H12	-3.144	1.308	.815
H13	-3.140	-1.317	.815
H13.5	-3.412	-1.494	.815
H14	-3.389	-1.564	.815
H15	-5.175	-2.658	.815
H16	-5.175	1.306	.815
H17	-6.075	1.306	.815
H18	-6.075	4.030	.815
H19	-6.225	0.706	THRU
H20	-5.775	0.706	THRU
H21	-5.775	-3.044	THRU
H22	-6.225	-3.044	THRU

Figure 14 RF Housing Nr. 2



HOLE	X	Y	Z	
A1•4	+-1.030	+-6.906	THRU	4-40 STI, LK .168
A2•4	+-3.440	+-6.906	THRU	THRU
A3•4	+-6.906	+-3.090	THRU	16 PLCS
A4•4	+-6.906	+-1.030	THRU	
A5	0.628	3.107	THRU	ø.125 THRU
A6	3.166	0	THRU	ø.225 CB x 15 OP ↑
A7	0.652	-3 102	THRU	5 PLCS
A8	-2.703	-1.656	THRU	
A9	2.703	1.656	THRU	
B1•4	+-2.5	+-6 61	42	4-40 STI, LK 168
B2•2	0	+-6.61	.42	THRU
B3•4	+-6 61	+-2 5	42	12 PLCS
B4•2	+-6.61	0	.42	
C1	-3.887	6.325	THRU	4-40 STI, LK .168
C2	-1.840	6.325	THRU	THRU
C3	-0.090	6.325	THRU	11 PLCS
C4	1.706	6.325	THRU	
C5	3.525	6.250	THRU	
C6	2.375	4.911	THRU	
C7	0.404	3.411	THRU	
C8	-2.531	2.097	THRU	
C9	-3.319	4 407	THRU	
C10	-1.135	3.044	THRU	
C11	-1.110	4 729	THRU	
D1•2	6 325	+-1 133	THRU	4-40 STI, LK 168
D2•2	6 325	+-2.633	THRU	THRU
D3•2	6 325	+-4.133	THRU	19 PLCS
D4•2	5.255	+-5.203	THRU	
D5•2	4 185	+-6 173	THRU	
D6•2	2.556	+-4 644	THRU	
D7•2	1.035	+-3.026	THRU	
D8•2	2 647	+-1 717	THRU	
D9	3.495	0	THRU	
D10•2	3.667	+-1 960	THRU	
E1	3.525	-6.250	THRU	4-40 STYI, LK 168
E2	1.706	-6 325	THRU	THRU
E3	- 213	-6 325	THRU	14 PLCS
E4	-2 133	-6.325	THRU	
E5	-4 133	-6 325	THRU	
E6	-5 229	-5 229	THRU	
E7	-6.325	-4.133	THRU	
E8	-4.592	-3 034	THRU	
E9	-2 783	-2 038	THRU	
E10	-1 249	-2 897	THRU	
E11	0 418	-3 418	THRU	
E12	2.292	-4 911	THRU	
E13	-0 416	-4 540	THRU	
E14	-3 177	-4 540	THRU	
F1	-5 370	-2 981	THRU	4-40 STI, LK 168
F2	-5 430	-0 819	THRU	THRU
F3	-5 430	1.051	THRU	11 PLCS
F4	-6 325	2 133	THRU	
F5	-6.325	4.133	THRU	
F6	-5 285	5.173	THRU	
F7	-4 273	6 103	THRU	
F8	-3.819	4 775	THRU	
F9	-3.393	3.337	THRU	
F10	-3 077	1 558	THRU	
F11	-3.082	-1 577	THRU	
G1	-6.171	-3 504	ø 400 THRU	

Figure 15 RF Housing Nr. 3

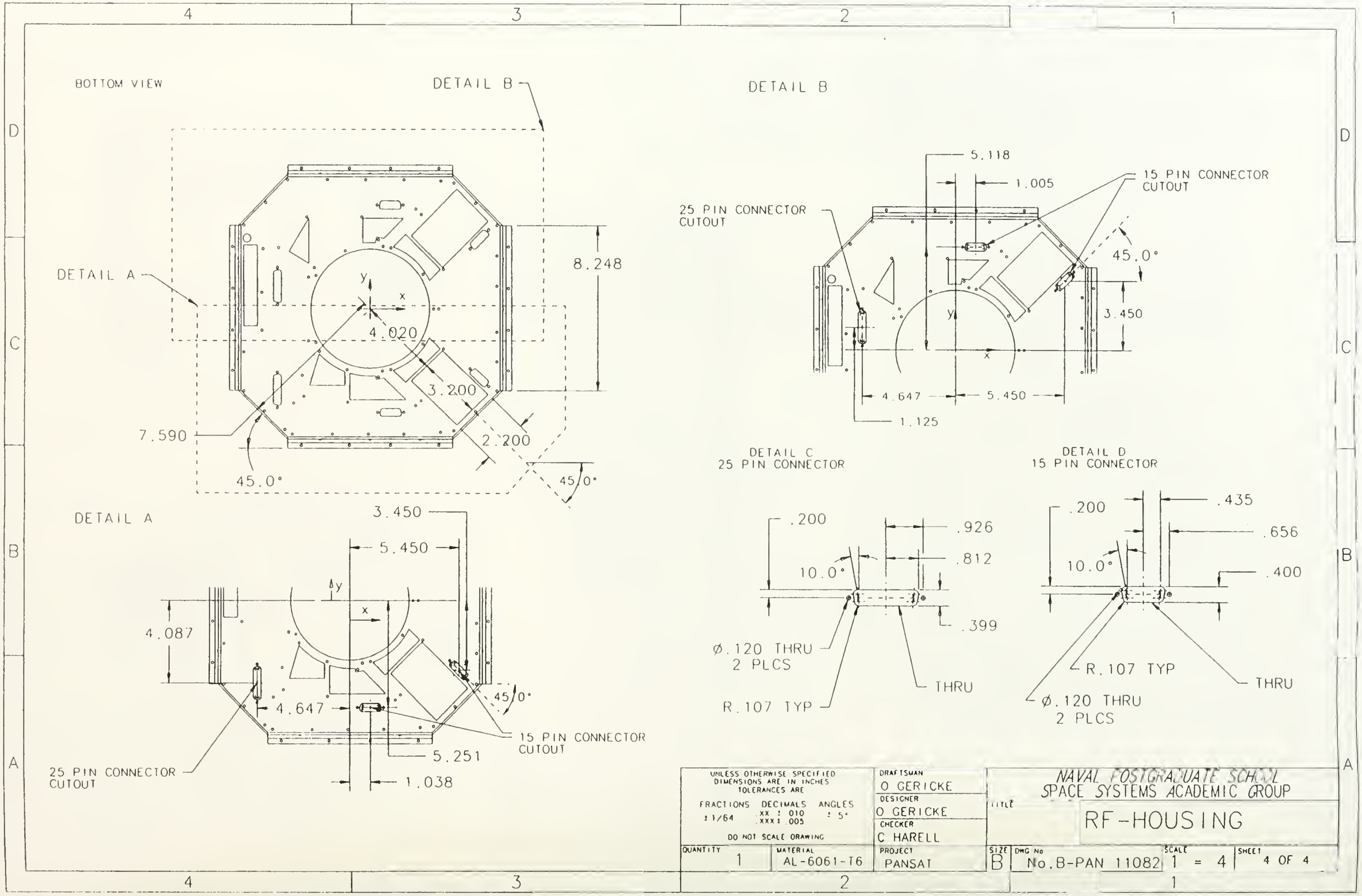
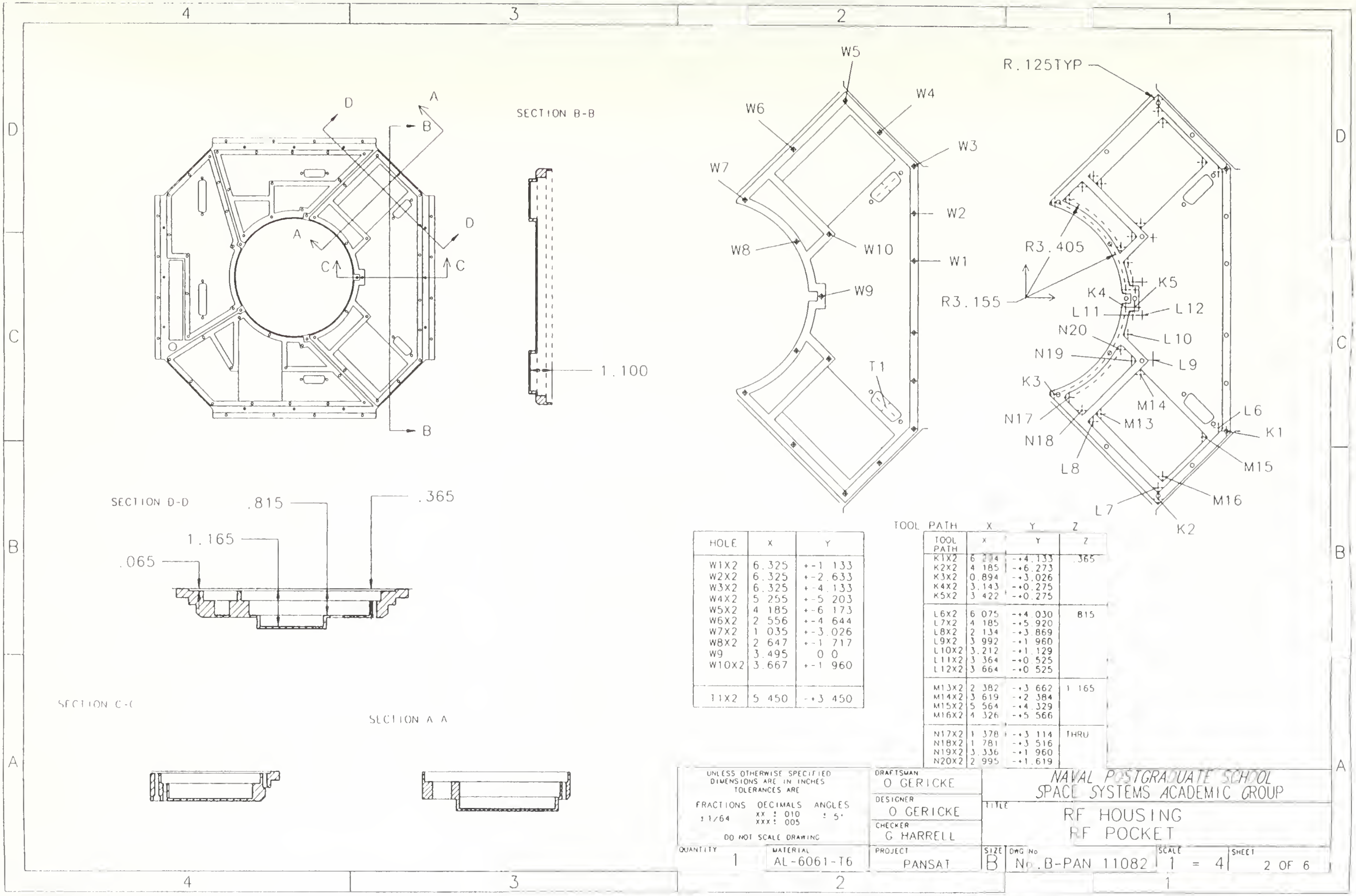


Figure 16 RF Housing Nr. 4

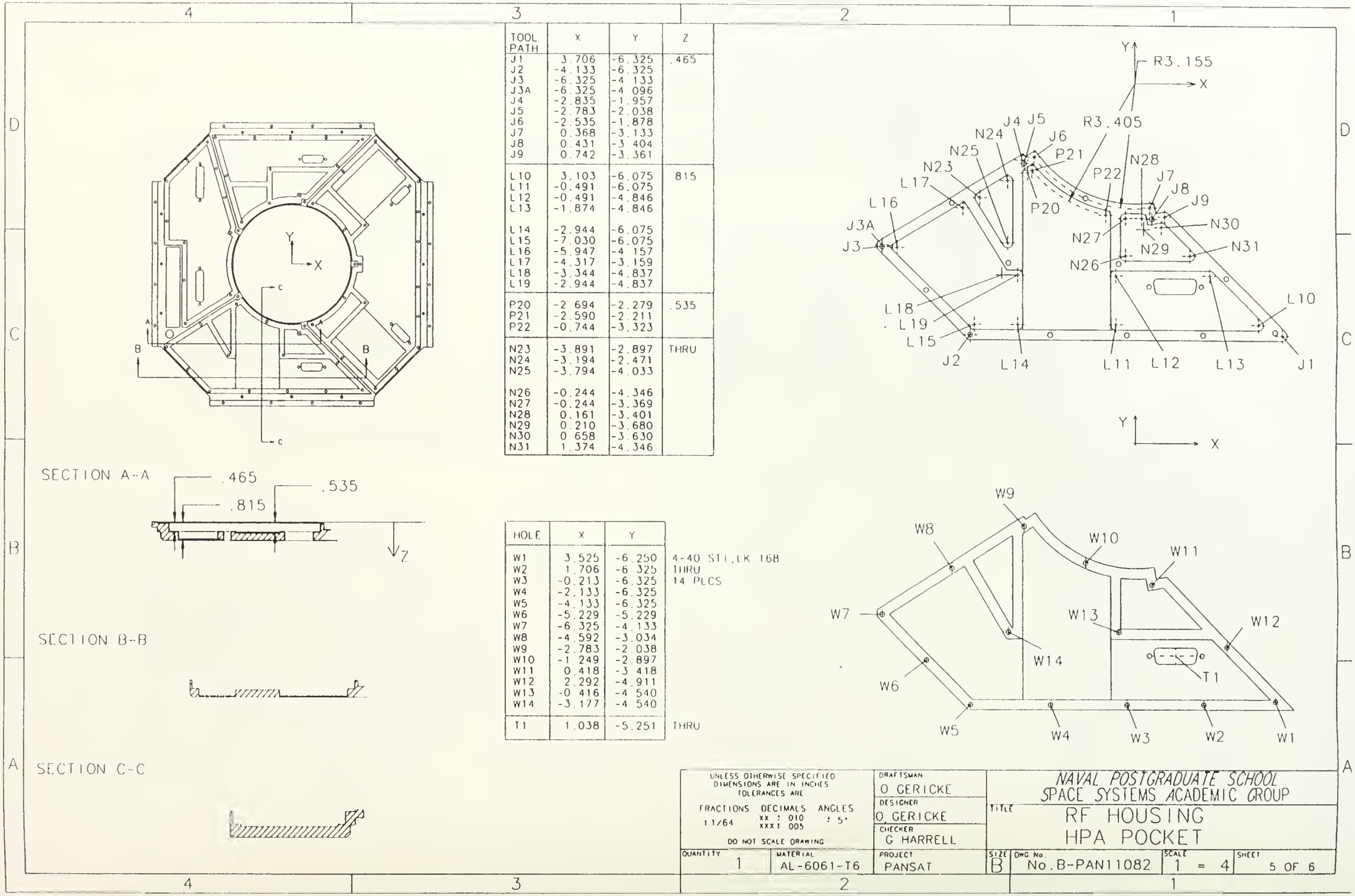


HOLE	X	Y
W1X2	6.325	+-1 133
W2X2	6.325	+-2.633
W3X2	6.325	+-4.133
W4X2	5 255	+-5 203
W5X2	4 185	+-6 173
W6X2	2 556	+-4 644
W7X2	1 035	+-3.026
W8X2	2 647	+-1 717
W9	3.495	0 0
W10X2	3.667	+-1 960
T1X2	5 450	-+3 450

TOOL PATH X Y Z

TOOL PATH	X	Y	Z
K1X2	6 [illegible]	-+4.133	.365
K2X2	4 185	-+6.273	
K3X2	0.894	-+3.026	
K4X2	3.143	-+0.275	
K5X2	3 422	-+0.275	
L6X2	6 075	-+4 030	815
L7X2	4 185	-+5.920	
L8X2	2 134	-+3.869	
L9X2	3 992	-+1 960	
L10X2	3.212	-+1.129	
L11X2	3 364	-+0 525	
L12X2	3 664	-+0 525	
M13X2	2 382	-+3 662	1 165
M14X2	3 619	-+2 384	
M15X2	5 564	-+4.329	
M16X2	4 326	-+5 566	
N17X2	1 378	-+3 114	THRU
N18X2	1 781	-+3 516	
N19X2	3.336	-+1 960	
N20X2	2 995	-+1.619	

Figure 16A RF Pocket



TOOL PATH	X	Y	Z
J1	3.706	-6.325	.465
J2	-4.133	-6.325	
J3	-6.325	-4.133	
J3A	-6.325	-4.096	
J4	-2.835	-1.957	
J5	-2.783	-2.038	
J6	-2.535	-1.878	
J7	0.368	-3.133	
J8	0.431	-3.404	
J9	0.742	-3.361	
L10	3.103	-6.075	.815
L11	-0.491	-6.075	
L12	-0.491	-4.846	
L13	-1.874	-4.846	
L14	-2.944	-6.075	
L15	-7.030	-6.075	
L16	-5.947	-4.157	
L17	-4.317	-3.159	
L18	-3.344	-4.837	
L19	-2.944	-4.837	
P20	-2.694	-2.279	.535
P21	-2.590	-2.211	
P22	-0.744	-3.323	
N23	-3.891	-2.897	THRU
N24	-3.194	-2.471	
N25	-3.794	-4.033	
N26	-0.244	-4.346	
N27	-0.244	-3.369	
N28	0.161	-3.401	
N29	0.210	-3.680	
N30	0.658	-3.630	
N31	1.374	-4.346	

HOLE	X	Y	
W1	3.525	-6.250	4-40 STI,LK 16B THRU 14 PLCS
W2	1.706	-6.325	
W3	-0.213	-6.325	
W4	-2.133	-6.325	
W5	-4.133	-6.325	
W6	-5.229	-5.229	
W7	-6.325	-4.133	
W8	-4.592	-3.034	
W9	-2.783	-2.038	
W10	-1.249	-2.897	
W11	0.418	-3.418	
W12	2.292	-4.911	
W13	-0.416	-4.540	
W14	-3.177	-4.540	
T1	1.038	-5.251	THRU

Figure 16B HPA Pocket

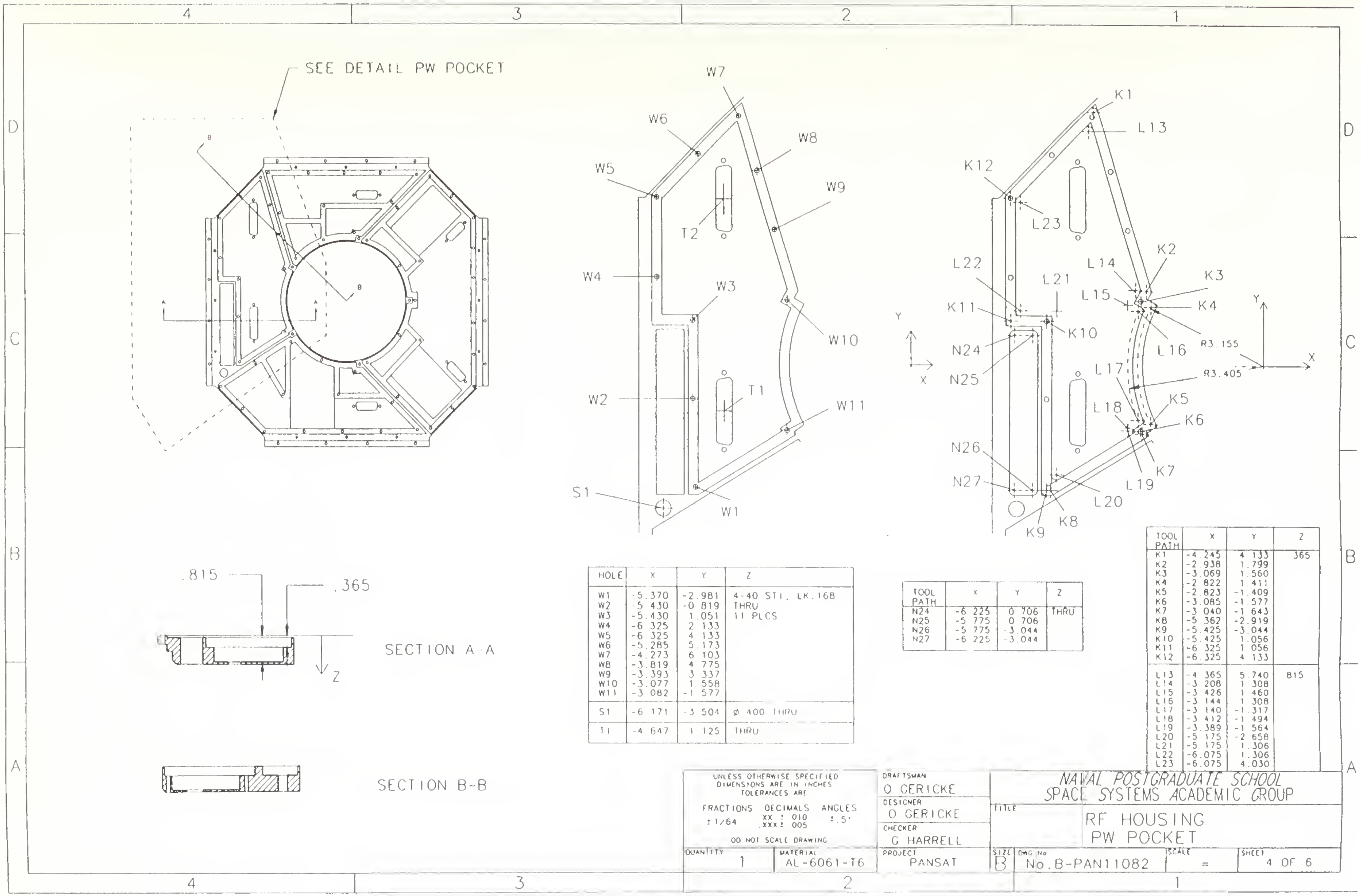
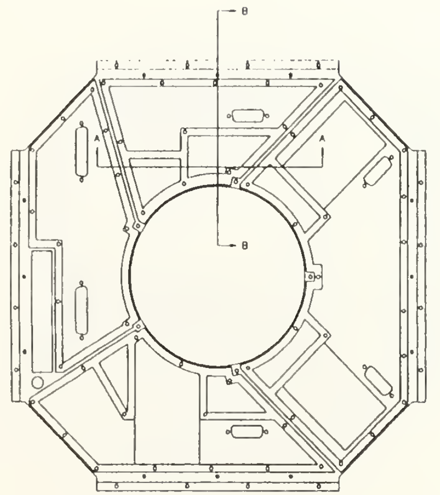
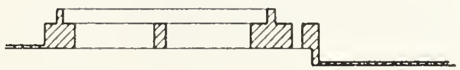
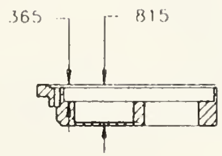


Figure 16C Power Pocket

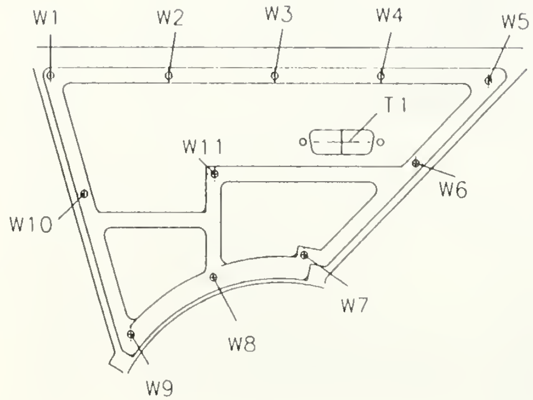




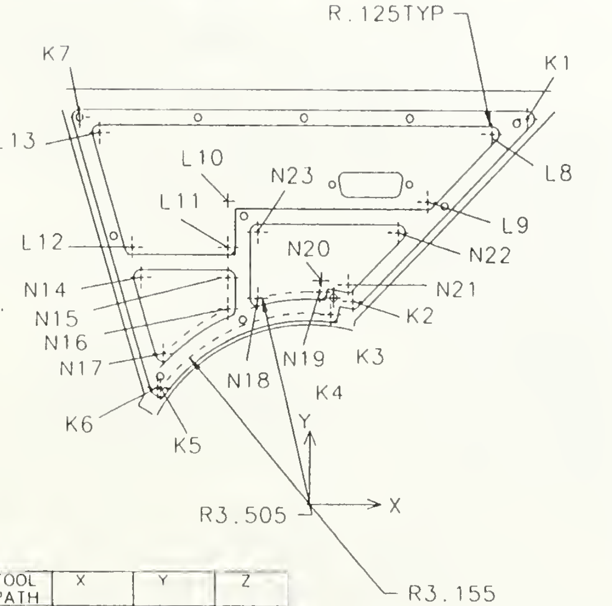
SECTION A-A



SECTION B-B



HOLE	X	Y	
W1	-3.887	6.325	4-40 STI. LK .268 THRU 11 PLCS
W2	-1.840	6.325	
W3	-0.090	6.325	
W4	1.706	6.325	
W5	3.525	6.250	
W6	2.375	4.911	
W7	0.404	3.411	
W8	-1.135	3.044	
W9	-2.531	2.097	
W10	-3.319	4.407	
W11	-1.110	4.729	
T1	+1.038	5.251	THRU



TOOL PATH	X	Y	Z
K1	+3.706	6.325	.365
K2	+.0734	3.352	
K3	+0.403	3.406	
K4	+0.355	3.135	
K5	-2.534	1.880	
K6	-2.578	1.905	
K7	-3.887	6.325	
L8	+3.103	6.075	.815
L9	+2.007	4.979	
L10	-1.385	4.979	
L11	-1.385	4.229	
L12	-3.006	4.229	
L13	-3.552	6.075	
N14	-2.857	3.729	THRU
N15	-1.385	3.729	
N16	-1.385	3.220	
N17	-2.485	2.472	
N18	-0.885	3.392	THRU
N19	+0.116	3.501	
N20	+0.199	3.621	
N21	+0.649	3.621	
N22	+1.507	4.479	
N23	-0.885	4.479	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE
FRACTIONS ±1/64 DECIMALS .XX ± .010 .XXX ± .005 ANGLES ±.5°
DO NOT SCALE DRAWING

QUANTITY 1 | MATERIAL AL-6061-T6

DRAFTSMAN O GERICKE
DESIGNER O GERICKE
CHECKER G HARRELL
PROJECT PANSAT

NAVAL POSTGRADUATE SCHOOL
SPACE SYSTEMS ACADEMIC GROUP

TITLE RF HOUSING
LNA POCKET

SIZE B | DWG NO. No.B-PAN 11082 | SCALE 1 = 4 | SHEET 3 OF 6

Figure 16D LNA Pocket

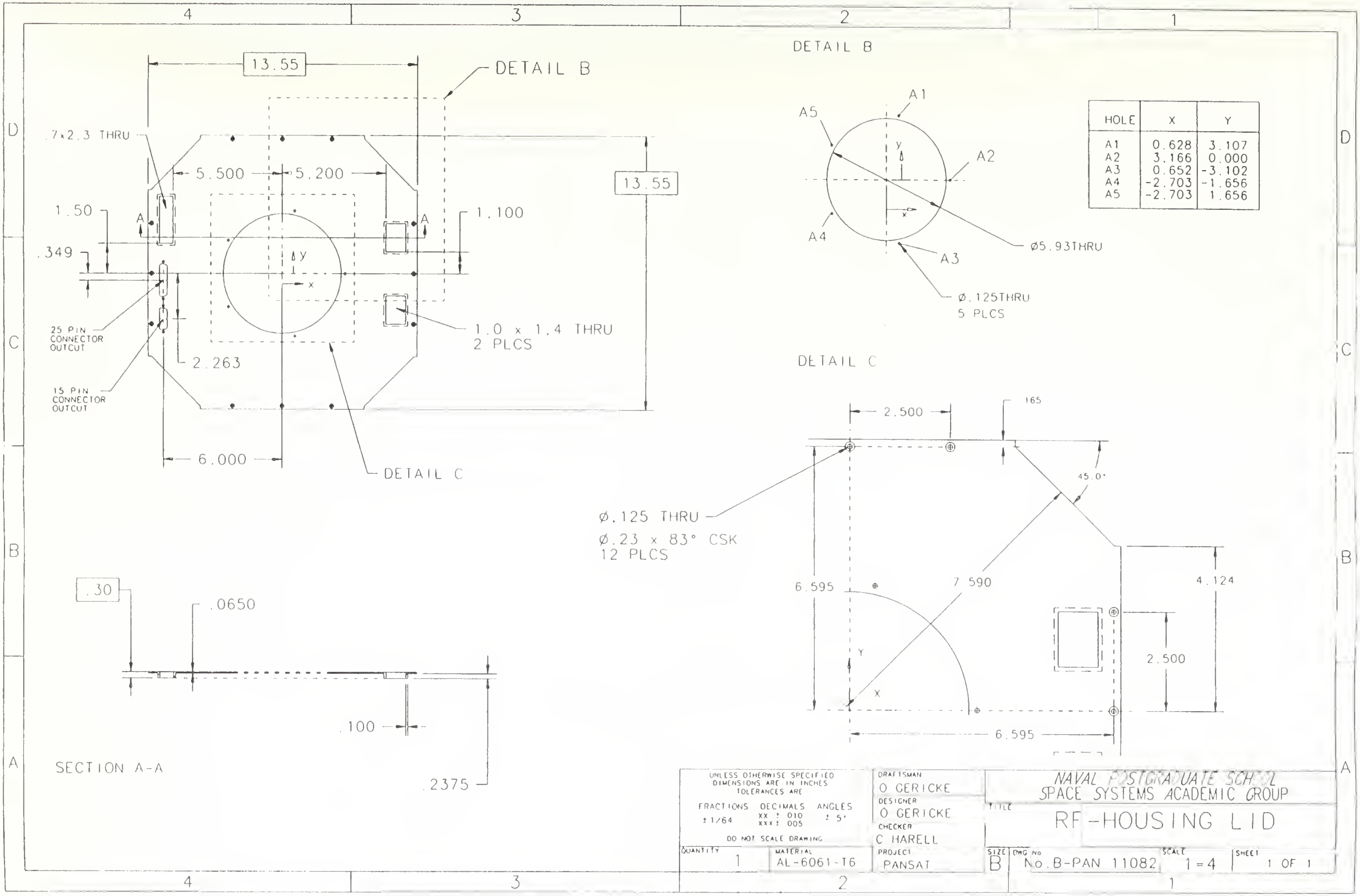
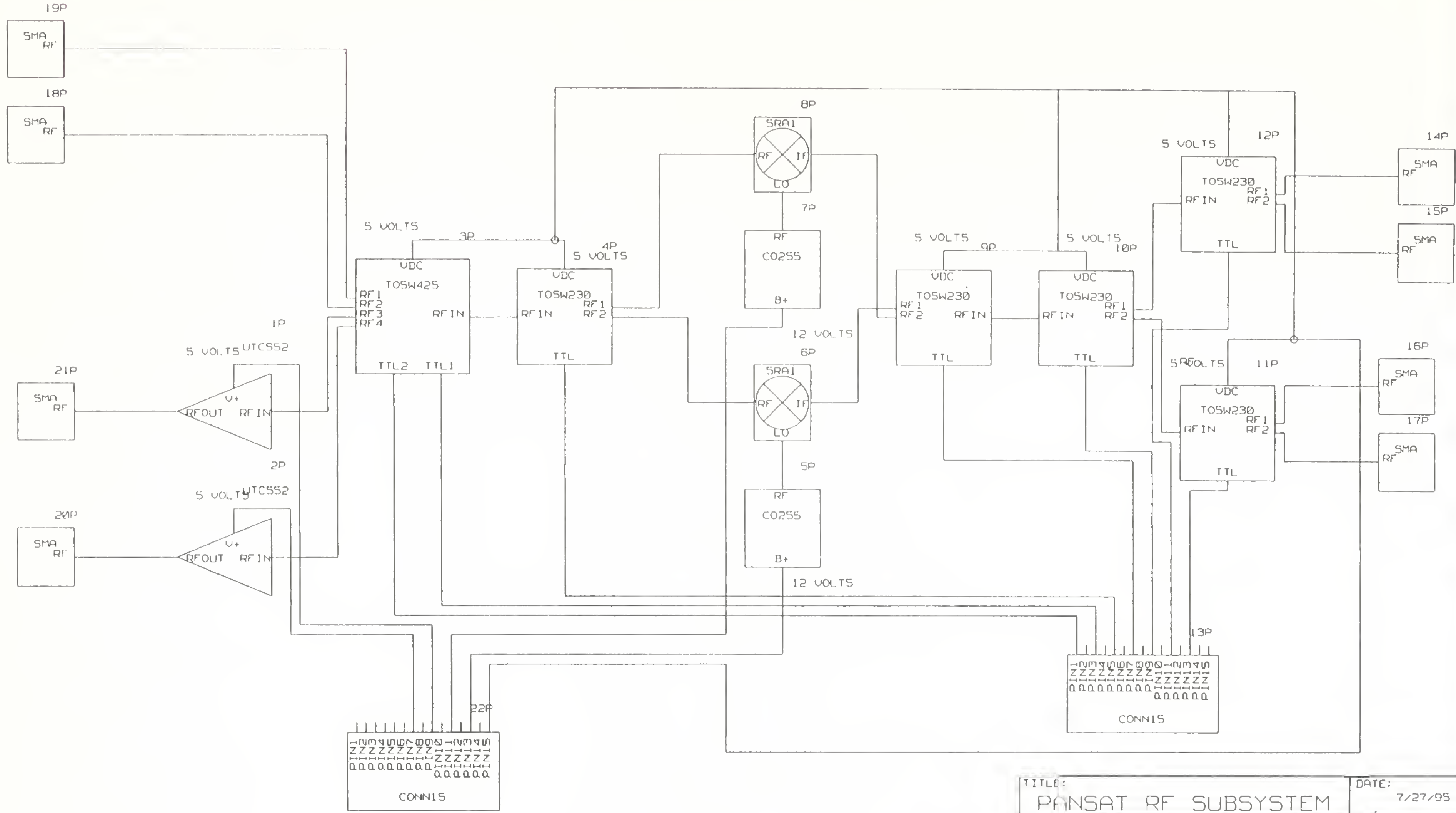


Figure 17 RF Lid - Drafting

APPENDIX D

SWITCHING SCHEMATICS

RF SWITCHING SCHEMATIC



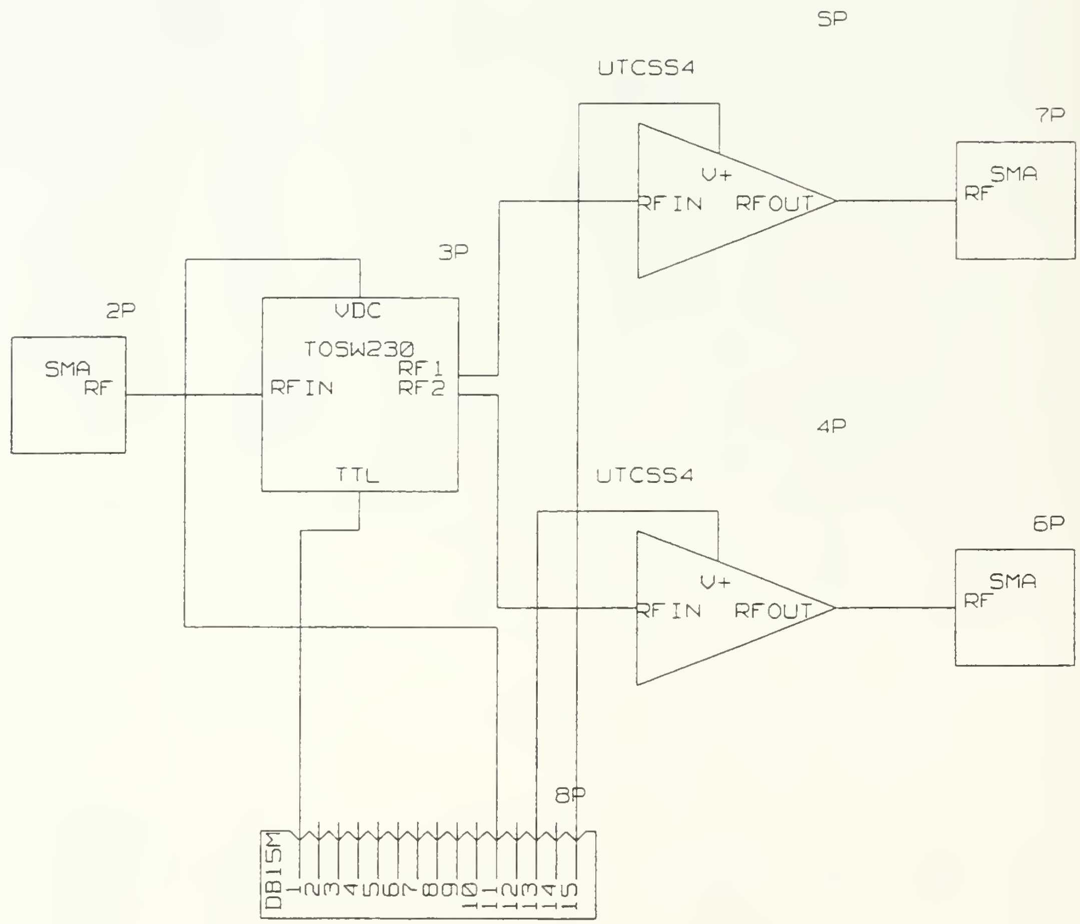
TITLE: PANSAT RF SUBSYSTEM

DATE: 7/27/95

ENGINEER: LAHT1

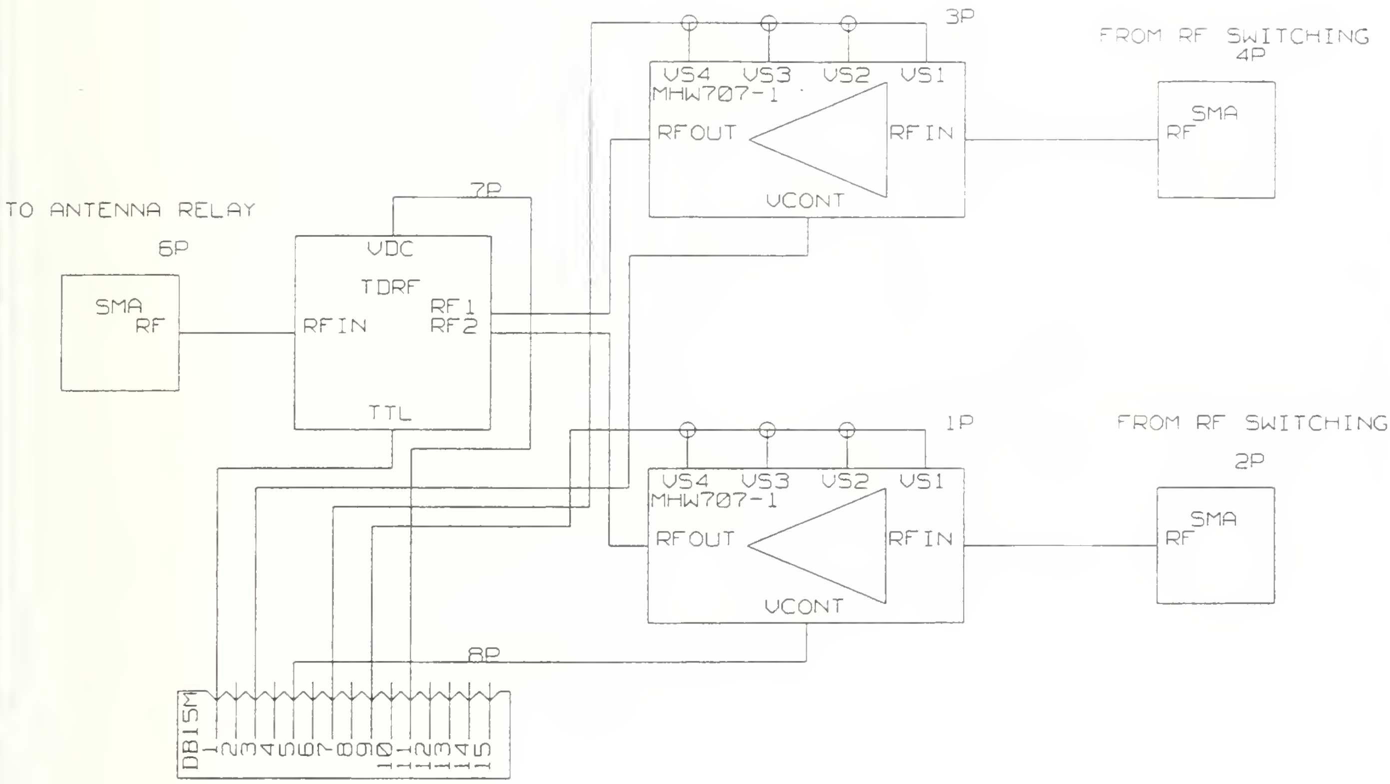
PAGE: 1 OF 1

LNA SCHEMATIC



TITLE: PANSAT RF SUBSYSTEM LNA ASSEMBLY	DATE: 8/9/95
ENGINEER: LAHTI	PAGE: 1 OF 1

HPA SCHEMATIC



TITLE: PANSAT RF SUBSYSTEM HPA ASSEMBLY	DATE: 8/9/95
ENGINEER: LAHTI	PAGE: 1 OF 1

APPENDIX E

FEA RESULTS

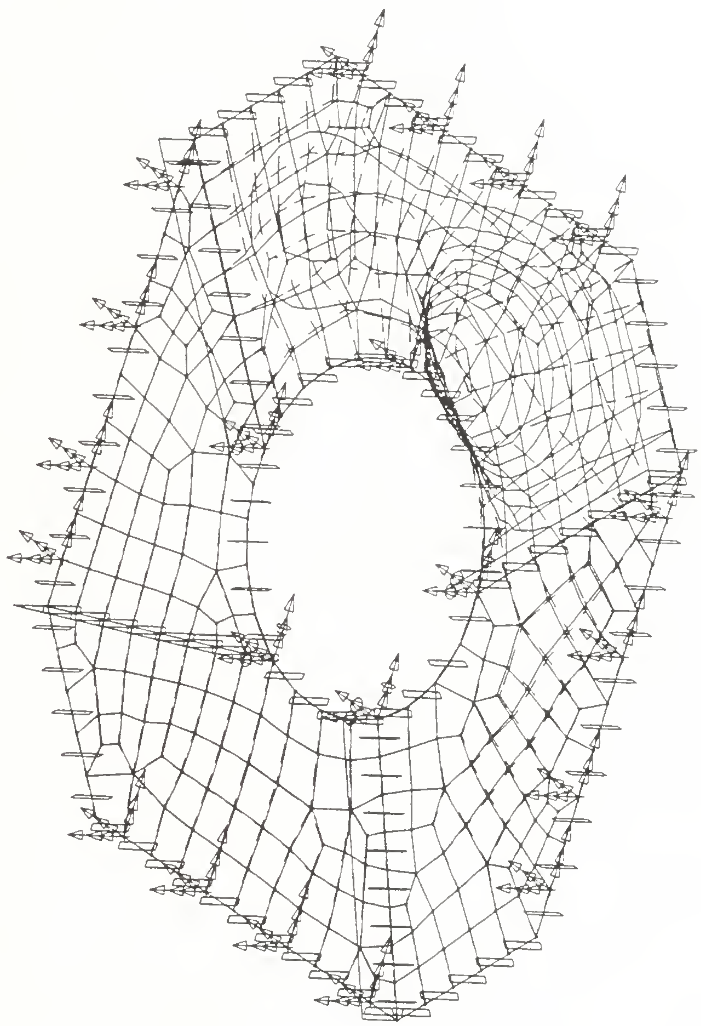


Figure 21 FEA Model RF Housing without loads

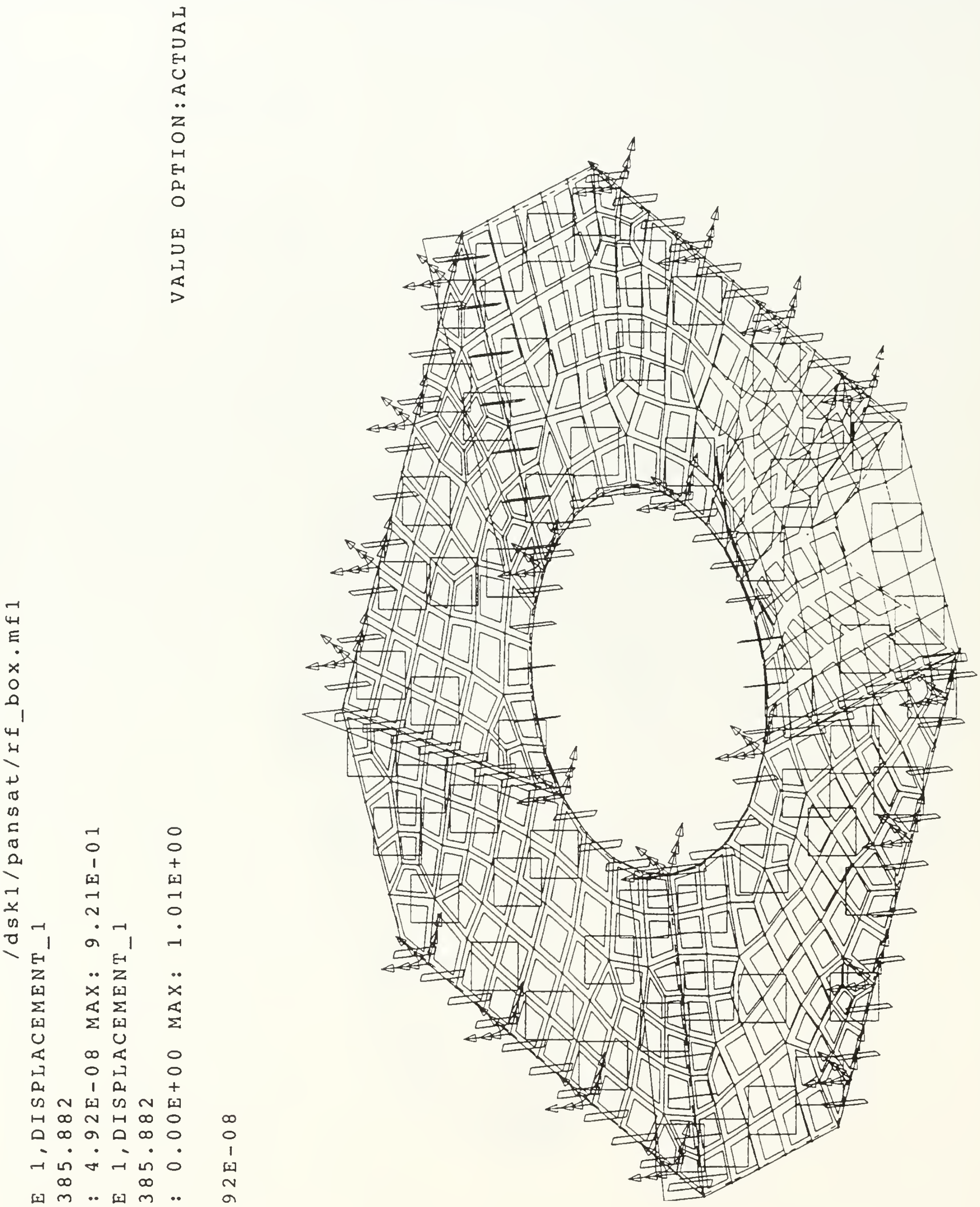


Figure 22 FEA Model RF Housing with loads

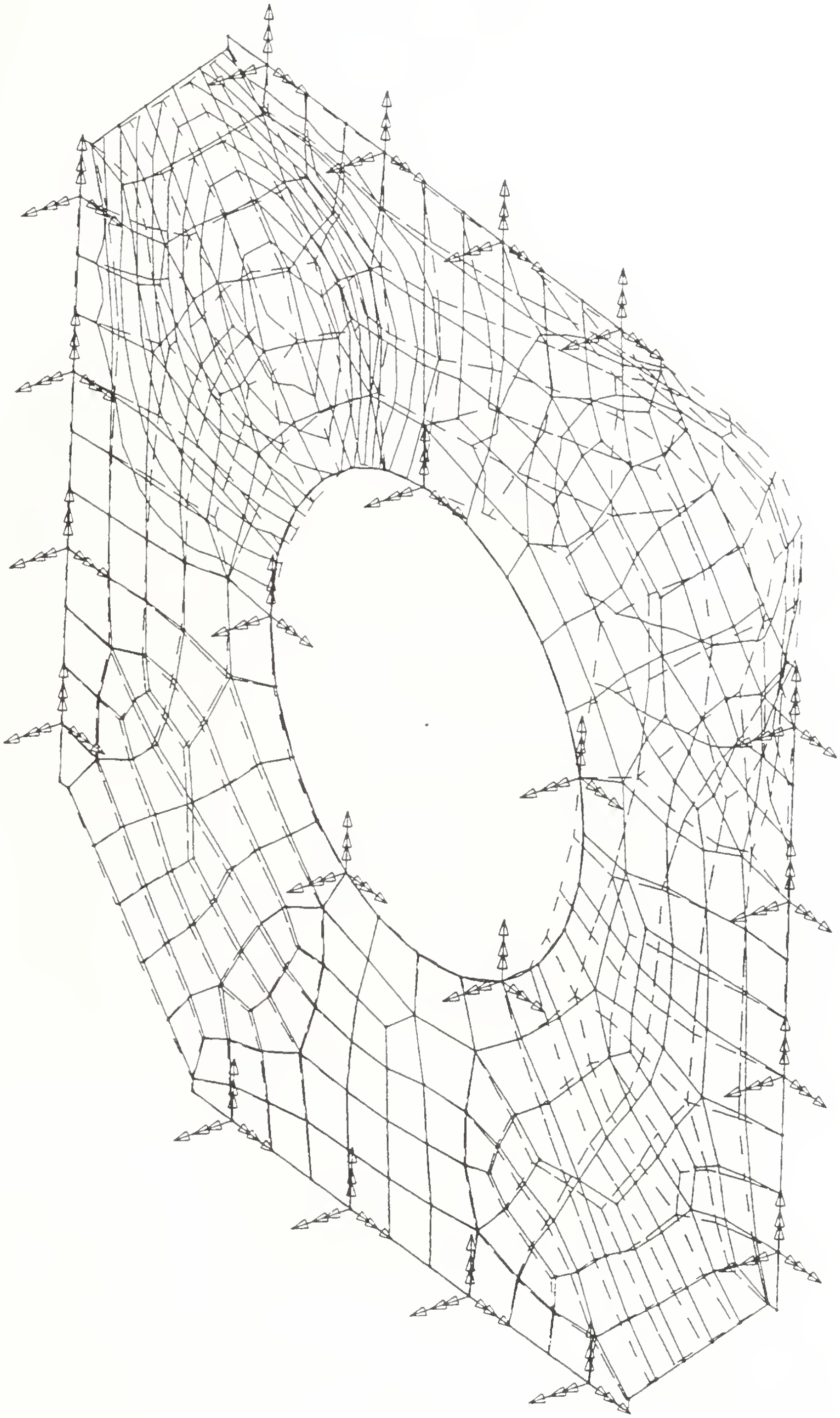


Figure 23 FEA Model RF Lid

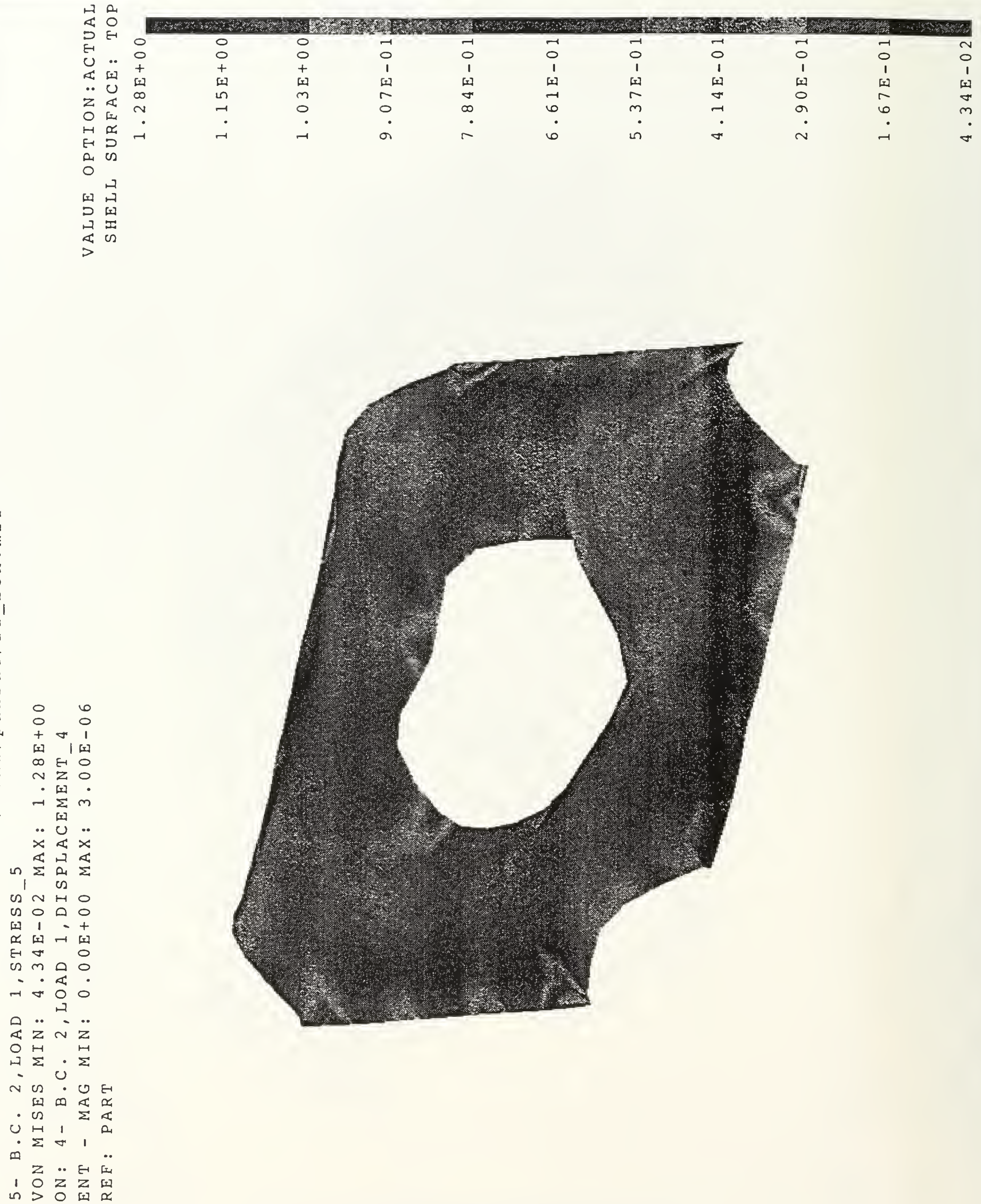


Figure 24 FEA Model RF Lid (von Mises Stress)

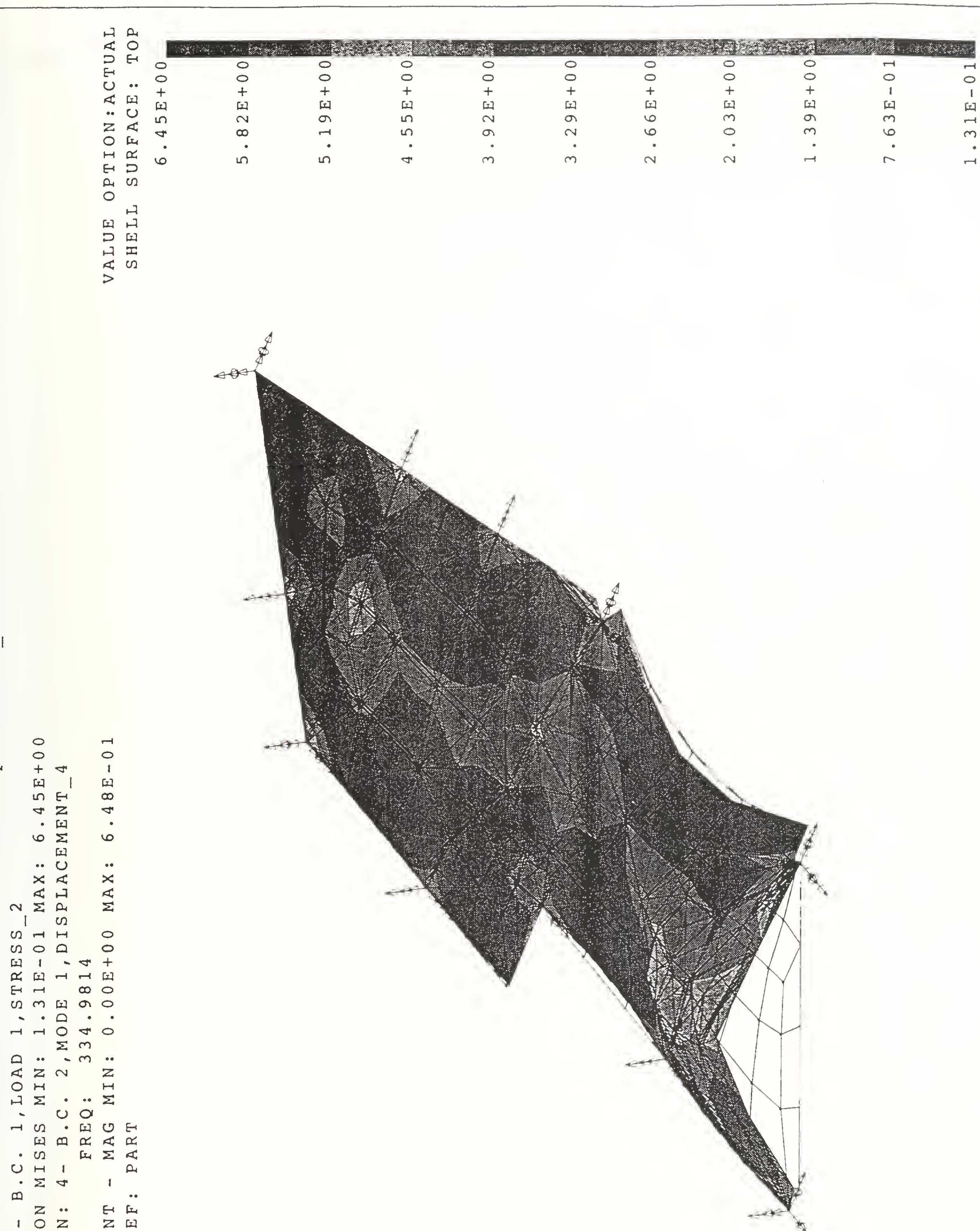


Figure 25 FEA Model LNA Board with loads

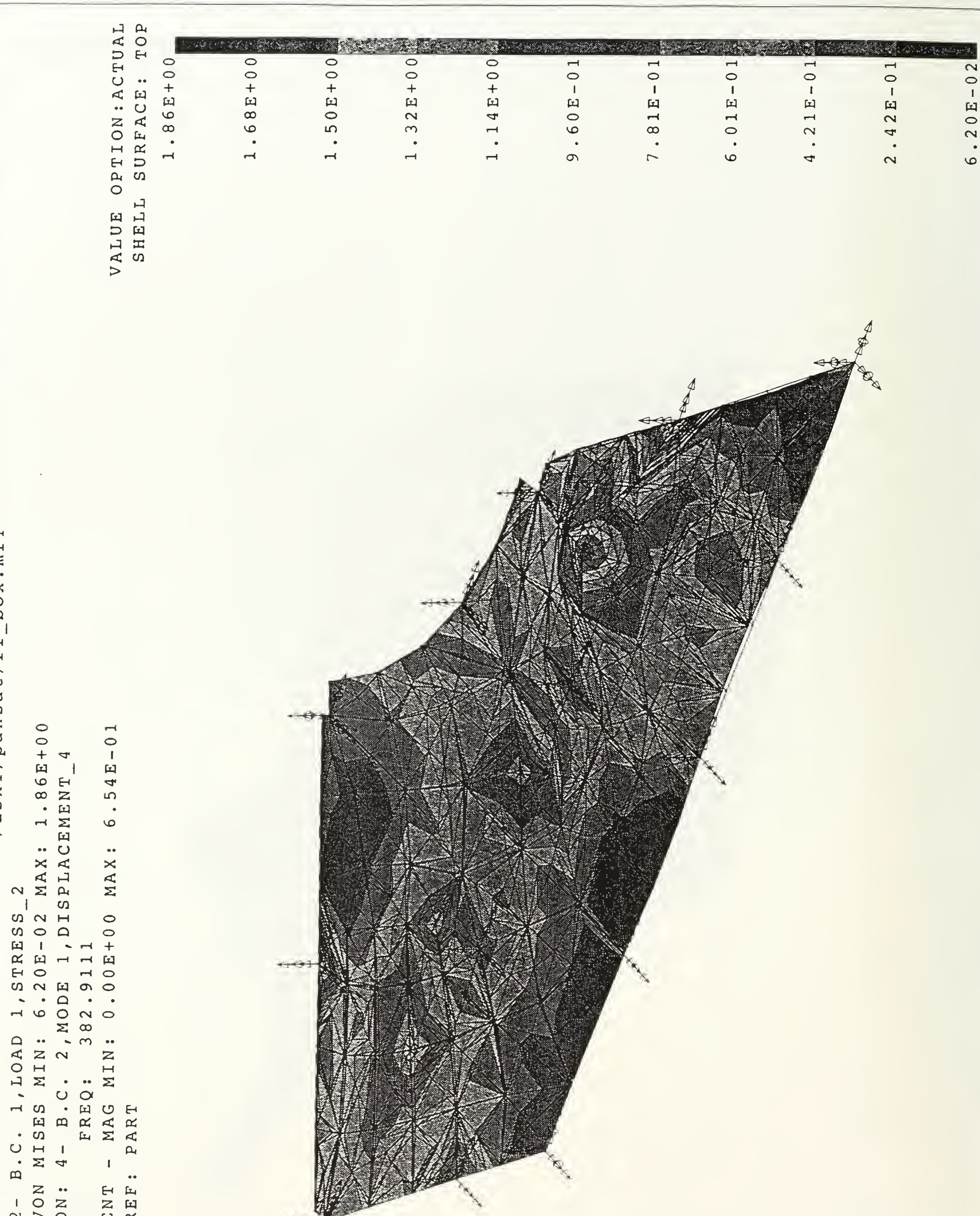


Figure 26 FEA Model RF Board with loads

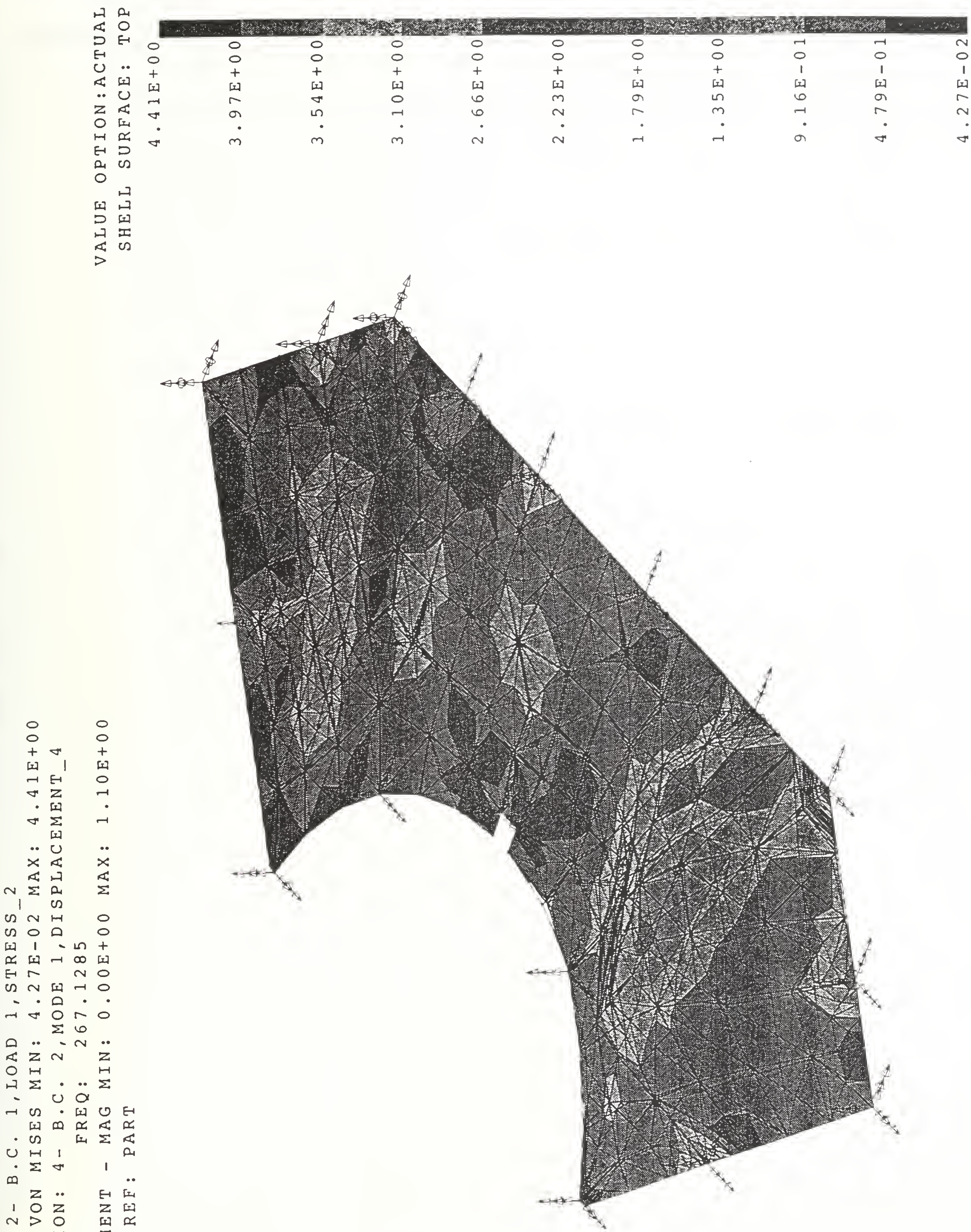


Figure 27 FEA Model HPA Board with loads

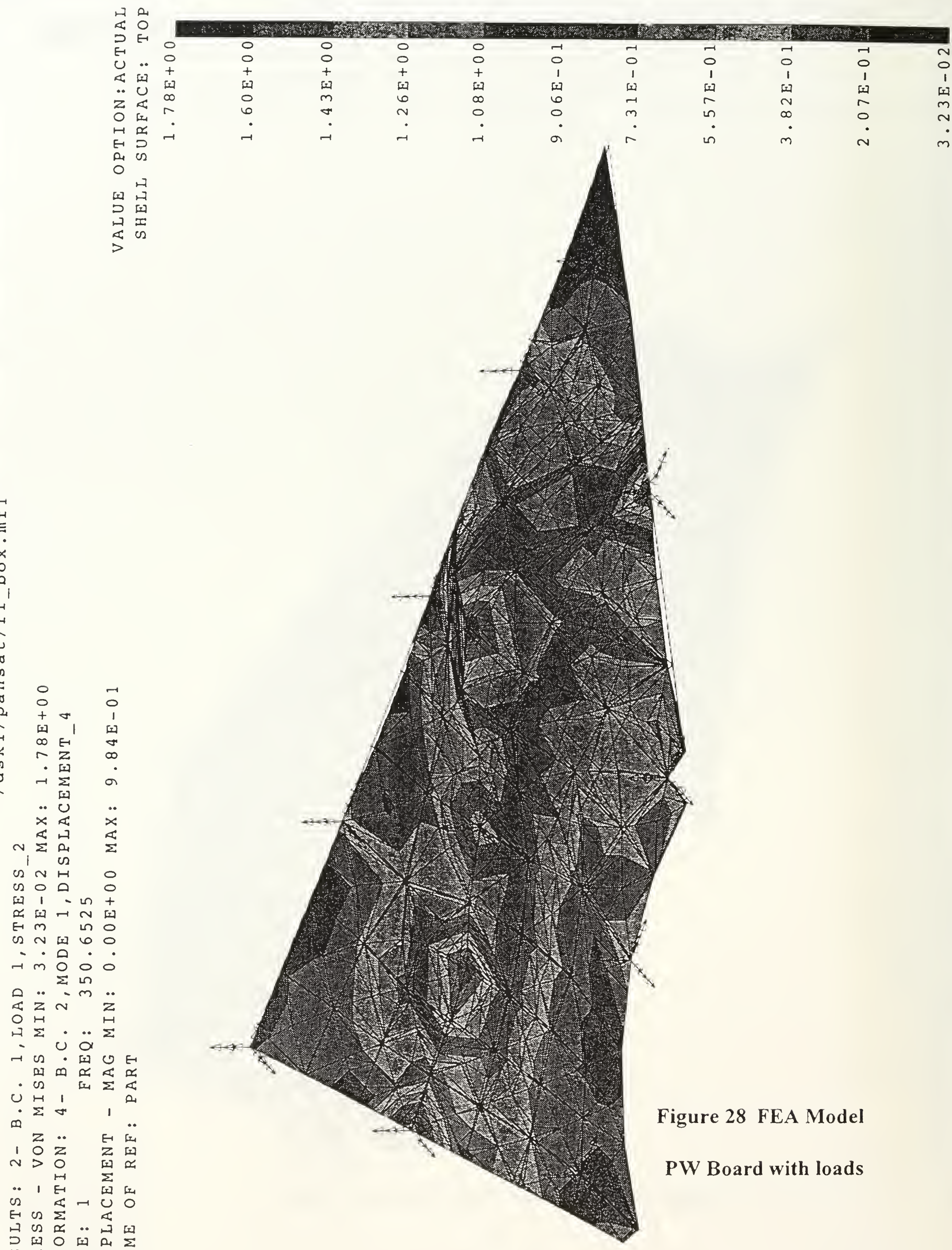


Figure 28 FEA Model

PW Board with loads

LIST OF REFERENCES

1. Hitchhiker Customer Accomodations & Requirements Specifications HHG-730-1503-07, *NASA Goddard Flight Center Greenbelt*, Maryland, 1994

2. EMI Shielding (Engineering Handbook), CHOMERICS, 1989

3. Structural Design and Analysis of the EPS Housing (PANSAT), Steve Tackett, Thesis May 1995

4. Vibration Analyses for Electronic equipment, *Dave S. Steinberg*, 1988

5. Structural Dynamics Research Corp., Finite Element Modeling User's Guide, 1990

6. Structural Design, Analysis and Modal Testing of PANSAT, D.J.Sakoda, Thesis Sept.1992

7. Spacecraft Systems Engineering, *Peter Fortescue and John Stark*, 1991

8. Satellite Technoology and its Applications (Spacecraft structure), *P.R.K. Chetty*, 1988

9. Structural Dynamics Research Corp., Test User's Guide, 1990

10. Get Away Special Payload Safty Manual, National Aeronautics and Space Administration, *Goddard Space Flight Center*, May 1986

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